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ABSTRACT

Water pollution techniques and practices, including data analysis, interpretation and display are described in this book intended primarily for the biologist inexperienced in this work, and for sanitary engineers, chemists, and water pollution control administrators. The characteristics of aquatic environments, their biota, and the effects of various pollutants upon them are discussed and illustrated by examples of field investigations involving organic wastes, silts, toxic wastes, mine drainages, eutrophication, and radioactive wastes. Separate chapters describe the biology of water supplies and sewage treatment. The nature and control of biological nuisances such as slimes are discussed. Bibliography. (Author/AL)

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THE PRACTICE OF WATER POLLUTION BIOLOGY

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FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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THE PRACTICE OF WATER POLLUTION BIOLOGY

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UNITED STATES DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DIVISION OF TECHNICAL SUPPORT
1969

FOREWORD

PROTECTION and enhancement of the Nation's waters in the face of continued pressures of population and industrial growth, urbanization, and technological change is a major task and challenge confronting us. A key to our success will be the extent to which we can define and understand the quality and behavior of the aquatic environment. The study of life in water is an essential part of that understanding. Determination of the effects of pollution upon the aquatic biota uses, and recognition and control of the plants and animals that create nuisances or costly problems are critical elements in the multifaceted scientific effort needed. This book, which is devoted to a comprehensive discussion of problem investigation and problem solving through the techniques of aquatic biology, will be a valuable contribution in assisting those who are involved in the applied aspects of water pollution control.

David D. Dominick

DAVID D. DOMINICK, *Commissioner*
Federal Water Pollution
Control Administration

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PREFACE

TO fulfill a need that has become apparent, this book presents some practical water pollution biological field investigative techniques and practices, procedures to solve problems, data analyses, interpretation and display, and the development and writing of the investigative report. It is written principally for the biologist inexperienced in these activities, and for sanitary engineers, chemists, attorneys, water pollution control administrators, and others who are interested in broadening their understanding of this discipline.

The book considers the many aquatic environments, their biotic constituents, and the effects of various pollutants upon them. Field investigations that include forming the study objectives, planning the field study, station selection, sample collection and examination, data analyses and interpretation, and reporting the results are described. Individual water quality constituents that affect the aquatic environment are discussed. Examples of field studies on specific water pollution problems are given with the collected data presented in many graphic variations. The ability to present a clear, understandable concept to the viewer by different methods of displaying data is evaluated. Examples of field investigations, with which the author has been involved, including data collection, analyses, interpretation and display are given for organic wastes, silts, toxic wastes, acid mine drainages, eutrophication, and radioactive wastes. Investigations in marine waters are discussed. Separate chapters detail the biology of municipal water supplies and sewage treatment. Biological nuisances and slimes are discussed, as well as their control.

In presenting the book's contents, over 20 years of biological field investigative experience are represented in the described field and laboratory methods, report writing, and data display. Methodology modifications presented may be of value to other professional biologists. Because the results from most problem solving investigations must be presented to the lay public to engage their support for remedial actions, reporting and data display must be clear and readily understandable. Clearness and understandability have been goals of this book.

Washington, D.C.
September, 1969

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The assistance of past and present coworkers from the many disciplines within the National Field Investigations Center, FWPCA, was an essential contributing factor to the gathering of information and the development of studies presented here. Team effort has become a byword of the Center and the "team" included engineers, chemists, biologists, microbiologists, technicians, secretaries, and administrators.

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1

STAGE SETTING

WATER:
A necessity for life
A transporter of disease
A sustainer of navigation
A coolant, cleanser, diluent
A medium for recreational pursuits
A resource with food for populations
A power source to harness and control
A source of tranquil, aesthetic enjoyment
A refuge for biological pests and nuisances
A defiled purveyor of civilization's wastes

Water means different things to different people. A particular definition depends in large measure on the personal uses to which water is put by the definer. In this book the concern is not so much with specific water uses as it is with water quality and aquatic life, and the investigation of it.

A section in the National Technical Advisory Committee on Water Quality publication (Anon., 1968) states that, "It is not surprising that water has occupied an important position in the concerns of man. The fate of tribes and nations, cities and civilizations has been determined by drought and flood, by abundance or scarcity of water since the earliest days of mankind."

From the days of the earliest investigator it has been known that each water supports its particular life forms. As early as 1918 Henry Baldwin Ward wrote:

> "From the tiniest rivulet to the mightiest river one may find every possible intermediate stage, and between the swiftest mountain torrent and the most sluggish lowland stream there exists every intermediate gradation. Biologically considered, the torrent imposes on the development of life within its waters evident mechanical limitations which are not present in the slow-flowing streams. Ordinarily the

biological wealth of a stream varies inversely with its rate of flow, and anything which stops or checks the flow makes conditions more favorable for the development of life. Flowing waters are thinly inhabited and also present considerable difficulties to the student; hence they are relatively unexplored territory.

"Taken together lakes compose one-half the fresh water on the surface of the globe. They present an infinite variety of physical features in rocky, sandy, swampy margins, in steep and shallow shores, in regular and broken contours with no islands or many, with shallow water or depth that carry the bottom far below the level of the sea.

"They vary in the chemical character of the soil in the lake basin as well as in their banks and bed, in the degree of exposure to wind and sunshine, in the relative inflow and outflow in ratio to their volume, in their altitude as well as in geographic location. All of these and many other factors modify and control the types of living things and their abundance in the waters." (Ward and Whipple, 1918).

To continue the description of water quality in embellished terms, Mark Twain many years ago eulogized Lake Tahoe in this everlasting prose: [1]

> "In the early morning one watches the silent battle of dawn and darkness on the waters of Tahoe with a placid interest but when the shadows skulk away and one by one the hidden beauties of the shore unfold themselves in the full splendor of noon: When the smooth surface is belted like a rainbow with broad bars of blue and green and white, half the distance from circumference to center, when in the lazy summer afternoon, he lies in a boat far out to where the dead blue of the deep water begins and smokes the pipe of peace and idly winks at the distant crags and patches of snow from under his cap brim: When the boat drifts shoreward to the white water, and he lolls over the gunwale and gazes by the hour down through the crystal depths and notes the color of the pebbles and reviews the finny armies gliding in procession a hundred feet below: When at night he sees moon and stars, mountain ridges feathered with pines, jutting white capes, bold promontories, grand sweeps of rugged scenery topped with bald glimmering peaks, all magnificiently pictured in the polished mirror of the lake, in richest, softest detail the tranquil interest that was born with the morning deepens and deepens by sure degrees, till it culminates at last in resistless fascination."

Water quality affects man in his direct use of the water; it affects also the aquatic life that the water contains. Considering the latter, Shelford

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[1] From "Lake Tahoe Water Quality Control Policy," June 1966, prepared by State of California, The Resources Agency, Lahontan Regional Water Quality Control Board.

(1918) chose to phrase these aspects as "conditions of existence." He stated that conditions of existence are of importance only insofar as they affect the life and death processes of organisms. Earlier, Forbes (1887) noted the complexity and interrelationship of organism community studies in water quality explorations with the words, "If one chooses to become acquainted with the black bass . . . he will learn but little if he limits himself to that species." Forbes further called attention to the close community of interest that exists among species with the reasoning that to exist a species birth rate must at least equal its death rate and that when a species is preyed upon by another it must produce regularly an excess of individuals for this destruction. Forbes went on to say that on the other hand the dependent species must not appropriate, on the average, any more than the excess of individuals upon which it preys. He argued that the common interest among species was promoted by the process of natural selection.

Figure 1. Lake Tahoe: A Jewel of the West

Aquatic biology, the subject of this discussion, is only one of many disciplines involved in water quality investigations. Other disciplines include chemistry, microbiology, engineering, hydrology, and geology.

The early chronicle of published biological effort began with Hassall in 1850 (1850, 1856) who noted the value of microscopic examination of water for the understanding of water problems. Sedgwick (1888) applied biological methods to water supply problems. Under his leadership the Massachusetts State Board of Health was the first agency in the United States to establish a systematic biological examination of water supplies. In 1889, Sedgwick collaborated with George W. Rafter to develop the Sedgwick-Rafter method of counting plankton. Whipple (1899) produced a treatise that, in 1948, was in its fourth edition and fifth printing; it has served through the years as an often-used reference in the water supply and water pollution field.

One of the first practical applications of biological data to the biological definition of water pollution was contained in the "saprobien system" of Kolkwitz and Marsson (1908, 1909). This system, based on a check list detailing the responses of many plants and animals to organic wastes, has been used extensively to indicate the degree of pollution at a given site. That the sound basic judgment of these early investigators has withstood the passage of time is shown by the frequent references currently made to their works.

The survey of the Illinois River by the Illinois Natural History Survey was one of the first studies that demonstrated clearly the biological effects of organic pollution; these studies were presented in a series of papers that provided much impetus and professional status to biological stream investigations in the United States (Forbes and Richardson, 1913, 1919; Forbes, 1928). Richardson (1921) described changes that had occurred in the bottom fauna of the Illinois River since 1913 resulting from increased movement of sewage pollution southward. Later, Richardson (1928) noted that ". . . the number of small bottom-dwelling species of the fresh waters of our distribution area that can be safely regarded as having even a fairly dependable individual index value in the present connection is surprisingly small; and even those few have been found in Illinois to be reliable as index species only when used with the greatest caution and when checking with other indicators."

Purdy (1916) demonstrated the value of certain organisms to indicate areas of pollution in the Potomac River receiving sewage discharges. The shallow flats of the Potomac River were found to be of great importance in the natural purification of organic wastes; sunlight and turbidity were observed to be prominent factors in the determination of oxygen levels and in waste purification processes. Weston and Turner (1917), Butterfield (1929), and Butterfield and Purdy (1931) reported other studies that demonstrated the effects of organic enrichment on streams, the sudden change in the biota after the introduction of the waste, and the progressive recovery of the biota downstream as the wastes were utilized.

Butcher (1932, 1940) studied the algae of rivers in England and noted that attached algal forms gave the most reliable indication of the suitability of the environment of an area for the support of aquatic life. In the United States, Lackey (1939, 1941a, 1942) investigated planktonic algae and noted their response to various pollutants. The work of Ellis (1937) on the detection and measurement of stream pollution, the effects of various wastes on stream environments, and the toxicity of various materials to fishes has served as a reference handbook and toxicity guide through many years.

Cognizance has been taken of the biotic community and the effect of pollution on the ecological relationships of aquatic organisms (Brinley, 1942; Bartsch, 1948). Bartsch and Churchill (1949) depicted the biotic response to stream pollution and related stream biota to zones of degradation, active decomposition, recovery, and clean water. Patrick (1949) described a healthy stream reach as one in which " . . . the biodynamic cycle is such that conditions are maintained which are capable of supporting a great variety of organisms," a semihealthy reach as one in which the ecology is somewhat disrupted but not destroyed, a polluted reach as one in which the balamce of life is upset, and a very polluted reach as one that is definitely toxic to plant and animal life. Patrick separated the biota into seven groups and illustrated specific group response to stream conditions with bar graphs. The number of species was used rather than the number of individuals. Fjerdingstad (1950) published an extensive list placing various algae and diatoms in zones or in ranges of stream zones similar to those of Kolkwitz and Marsson.

Epoch making water quality legislation in the Water Quality Act of 1965 that amended the Federal Water Pollution Control Act provided for the establishment of water quality standards for interstate (including coastal) waters.

Paragraph 3, section 10, of the Act reads as follows:

> "Standards of quality established pursuant to this subsection shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of this Act. In establishing such standards the Secretary, the Hearing Board, or the appropraite state authority shall take into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other legitimate uses."

Subsequent to this legislation the Federal Water Pollution Control Administration issued guidelines for establishing water quality standards for interstate waters. These policy guidelines included such statements as "Water quality standards should be designed to 'enhance the quality of water.' . . . No standards of water quality will be approved which provide for the use of any stream or portion thereof for the sole or principal purpose of transporting wastes . . . Numerical values should be stated for such quality characteristics where such values are available and applicable. Where appropriate, biological bioassay parameters may be used. In the absence of appropriate numerical values or biological parameters, criteria should consist of verbal descriptions in sufficient detail as to show clearly the quality of water intended."

On February 27, 1967, the Secretary of the Interior established the first National Technical Advisory Committee on Water Quality Criteria to the Federal Water Pollution Control Administration. The Committee's principal function was to collect in one volume a basic foundation of water quality criteria. A smaller but equally important function was to develop a report on research needs. In its published report the Committee recognized that there is an urgent need for data collection from systematic surveillance of waters and waste sources and for an expanded research effort (Anon., 1968). Systematic surveillance was defined as ". . . traditional sanitary surveys broadened to include aesthetic qualities . . .". The Committee's Report also underscored the relative value assigned to recreational use by the Act with statements that ". . . recreational uses of waters in the United States have historically occupied an inferior position in practice and law relative to other uses," but that today there is a growing realization that recreation is a full partner in water use; one that, with associated services, represents a multimillion dollar industry with substantial prospects for future growth, as well as an important source of psychic and physical relaxation. Water quality research needs including those assigned to fish, other aquatic life, and wildlife have been defined in a 1968 report of the National Technical Advisory Committee.

What, then, is a defined role of the field investigative water pollution biologist? Basically it seems apparent that the role of individuals working in this discipline is to:

1. Determine water quality compliance with established standards, and, determine the effectiveness of established standards to meet the needs of an enhanced water quality.
2. Identify, define, and interpret the effects on aquatic organisms of water quality changes that result from pollution.
3. Project these effects on man and man's use of the water.
4. Predict environmental conditions that might prevail, and beneficial water uses that would result, when pollution that can now be controlled is abated or alleviated, wholly or in some degree.
5. Determine impact of water quality on those important biotic community segments that are either harvestable directly by man or are essential to support more advanced levels of life within the aquatic environment.
6. Contribute to existing knowledge of the cause and control of pest and other nuisance aquatic organism populations.

2

AQUATIC ENVIRONMENTS

Features

AQUATIC environments are as numerous as the very waters themselves. Rising in snowcapped mountains small streams collect the snow melt and transport it to the plains. As these streams meander through the countryside they take from the lands that which is released to them. Small streams soon form larger ones that eventually join to form the great rivers and these in turn terminate in coastal estuaries. Each change in size and shape forms a habitat that becomes unique and supports an assemblage of organisms that is adapted to life in that particular environment. Reservoirs, built by man on rivers, in turn form a particular habitat that is influenced greatly by the reservoir's morphometric features. The reservoir in turn may influence the downstream environement because of the depth of the penstock that releases water of lower temperature, or of less dissolved oxygen, or of higher mineral quality, than the waters that receive it. The landscape is dotted with ponds and with many larger lakes of varying sizes and shapes. Each, as Professor Forbes pointed out many years ago, is a microcosm that supports its own organism community. The Great Lakes are at the pinnacle of lake environments within the United States, and because of their vast size, depths, and currents they offer many environments within their confines.

Organisms that may be found in great numbers in the stream environments are often not adapted to life within the lake or reservoir environments and vice versa. There are many features that tend to make a particular aquatic environement suitable or unsuitable, completely or to some degree, to a particular organism or group of closely associated organism.

Common to all aquatic environments would be the changes brought about by differences among the water habitats. For the pond and lake group these may include:

Altitude
Latitude
Area
Mean depth

Maximum depth
Area of different depth zones
Volume of different depth strata
Length of shoreline
Littoral slope
Drainage area
Runoff rate
Average inflow
Average outflow
Detention time
Water level fluctuation
Number of islands
Island areas
Island shoreline length
Penstock depth (reservoirs).

Features that create particular aquatic environments in flowing water may include:

Altitude
Latitude
Relative extent of pools and riffles
Depth at collection site
Width at collection site
Velocity of flow
Drainage area to collection site
Runoff rate
Physical composition of stream bed
Physical nature of surrounding terrain
Area geology.

The estuarine environment is influenced by morphometric features that are common to both the flowing water and static environments. In addition it is influenced by tidal cycles and their fluctuations.

Life in waters is influenced also by water temperatures, dissolved oxygen, pH, color, turbidities, total dissolved solids, total alkalinity, nutrients and mineral composition. Maximum values, and in some cases minimal values also, of these constituents often create an environment that becomes intolerable to particular organisms and will limit their production or interfere subtly with physiological processes that in turn reduce their ability to compete with others within the environment.

Pollutional Effects

Effects of pollution assume many characteristics and an infinitesimal variaton in degree when pollution enters the aquatic environment. The specific environmental and ecological responses to a pollutant will depend largely on the volume and strength of the waste and the volume of water receiving it. As a basic introduction, five types of responses will be described in subsequent paragraphs, and within each of these response types there can be many changes in magnitude and degree.

The classic response that has often been described in the literature is the effects of organic wastes that may be discharged from sewage treatment plants and certain industries. As these wastes enter the water they create turbidity, decrease light penetration, and may settle to the bottom in substantial quantity to form sludge beds. The wastes are attacked immediately by bacteria and this process of decomposition consumes oxygen from the water and liberates essential nutrients that in turn stimulate the production of some forms of aquatic life.

Pollutional Zones

Upstream from the introduction of organic wastes, classic description details a clean water zone or one that is not affected by pollutants. At the point of waste discharge and for a short distance downstream there is formed a zone of degradation where wastes become mixed with the receiving waters, and where the initial attack is made on the waste by bacteria and other organisms in the process of decomposition.

Following the zone of degradation there is a zone of active decomposition that may extend for miles, or days of stream flow, depending in large measure on the volume of dilution that is afforded the waste by the stream, and the temperature of the water. The biological processes that occur within this zone are similar in many respects to those that occur in a "typical" sewage treatment plant. Within this zone, waste products are decomposed and those products that are not settled as sludge are assimilated by organisms in life processes.

A zone of recovery follows the zone of active decomposition. The recovery zone is essentially a stream reach in which water quality is grad-

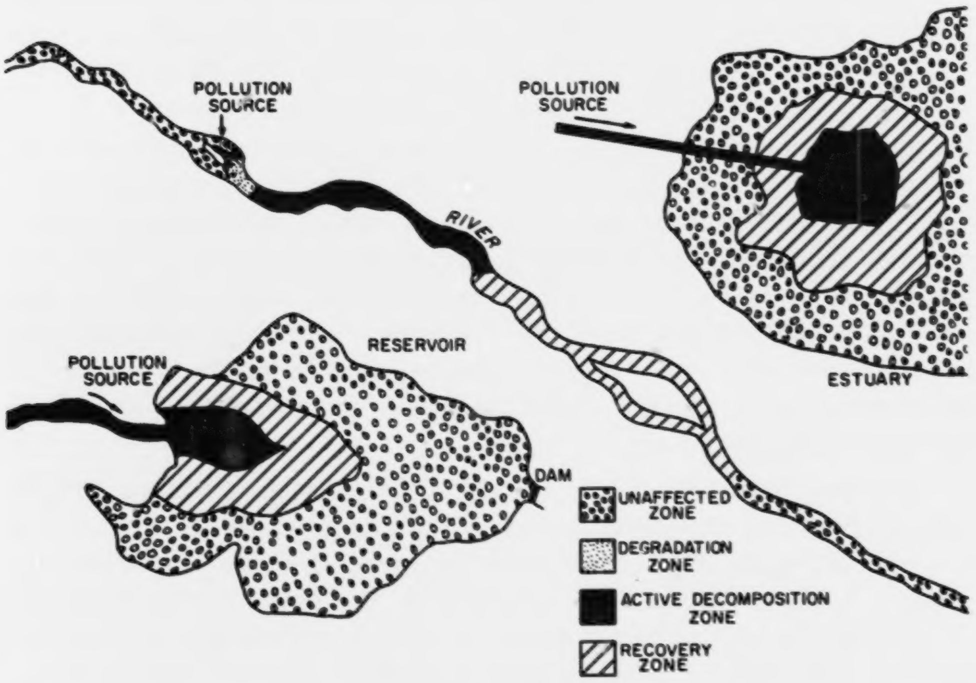


Figure 2. Pollutional Zones

ually returned to that which existed prior to the entrance of pollutants. Water quality recovery is accomplished through physical, chemical, and biological interactions within the aquatic environment. The zone of recovery may extend also for many miles and its extent will depend principally upon morphometric features of the waterway.

Finally the zone of recovery will terminate in another zone of clean water or area unaffected by pollution that is similar in physical, chemical, and biological features to that which existed upstream from the pollution source.

Organic Wastes

The classic description of the effects of organic wastes on the receiving stream often becomes confused in a specific stream investigation, because additional sources of pollution may enter the environment before the receiving water has been able to assimilate the entire effects of an initial source. When this occurs the effects of subsequent introductions become superimposed on those of the initial source and the total effect may confine large reaches of stream to a particular zonal classification.

Effects of organic wastes in the static water environment, as opposed to the flowing water environment, are modified principally by the morphometric features of the receiving water. Zonal changes that have been described for flowing water do exist but may be compressed in great measure either laterally or vertically when the discharge is to a lake or estuary. Such compression may tend to decrease the severity of pollution that is often observed in the flowing water environment and, on the other hand, may increase substantially the development of biotic nuisances such as algae or rooted aquatic plants that may develop from the nutrients released with and decomposed from the introduced organic materials.

Organism communities that may be related to pollution principally are those that are by nature associated with the bed or bottom of the waterway; those that attach themselves to objects such as rocks, aquatic plants, brush or debris submerged within the water; those that are essentially free floating and are transported by currents and wind, such as plankton and other microscopic forms; and those motile free swimming organisms such as fish. Considering each of these common organism groups, a number of observations can be made on their reaction to the introduction of organic wastes to a flowing stream.

Upstream from the waste source such limiting factors as food and intense competition among organisms and among organism groups, predation, and available habitat for a particular species will limit organism populations to those that can be sustained by the particular environment. Most often the limiting factor will be available food. Within this population, however, there will exist a great number of organism species. Thus, the old biological axiom for an environment unaffected by pollution is one that supports a great number of species with the total population delimited largely by food supply.

Following the introduction of organic wastes, conditions of existence for many organisms become substantially degraded. Increased turbidity in the water will reduce light penetration that in turn will reduce the volume of water capable of supporting photosynthesizing plants. Particulate matter in settling will flocculate small floating animals and plants from the water. As the material settles, sludge beds are formed on the stream bed and many of the areas that formerly could have been inhabited by bottom associated organisms become covered and uninhabitable.

The zone of degradation is a transition area between the clean water unaffected reach and a zone of decomposition of organic wastes. In such, the dissolved oxygen may be diminished but not completely removed. Sludge deposits may be initiated but are not formed in maximum magnitude or extent. Conditions of existence become impaired and typically there is a reduction in both the organism population and the number of species that can tolerate this environment.

Within the zone of active decomposition conditions of existence for aquatic life are at their worst. The breakdown of organic products by bacteria may have consumed available dissolved oxygen. Sludge deposits may have covered the stream bed thus eliminating dwelling areas for the majority of bottom associated organisms that could be found on an unaffected area. Fish spawning areas have been eliminated, but perhaps fish are no longer present because of diminished dissolved oxygen and substantially reduced available food. Here, aquatic plants will not be found in large numbers because they cannot survive on the soft shifting blanket of sludge. Turbidity may be high and floating plants and animals destroyed. Water color may be substantially affected. When organic materials are decomposed a seemingly inexhaustible food supply is liberated for those particular organisms that are adapted to use this food source. Thus, bacterial and certain protozoan populations may increase to extremely high levels. Those bottom associated organisms such as sludgeworms, bloodworms, and other worm-like animals may also increase to tremendous numbers because they are adapted to burrowing within the sludge, deriving their food therefrom, and existing on sources and amounts of oxygen that may be essentially nondetectable by conventional field investigative methods. Within the zone of active decomposition the organism species that can tolerate the environment are reduced to extremely low levels. Under some conditions those bottom associated animals that are visible to the unaided eye may be completely eliminated. Because of the tremendous quantity of food that is available to those organisms that are adapted to use it, the numbers of individuals of the surviving species may, indeed, be great. For example, it may be possible to find 50,000 sludgeworms or more living within each square foot of bottom area with the above-described conditions.

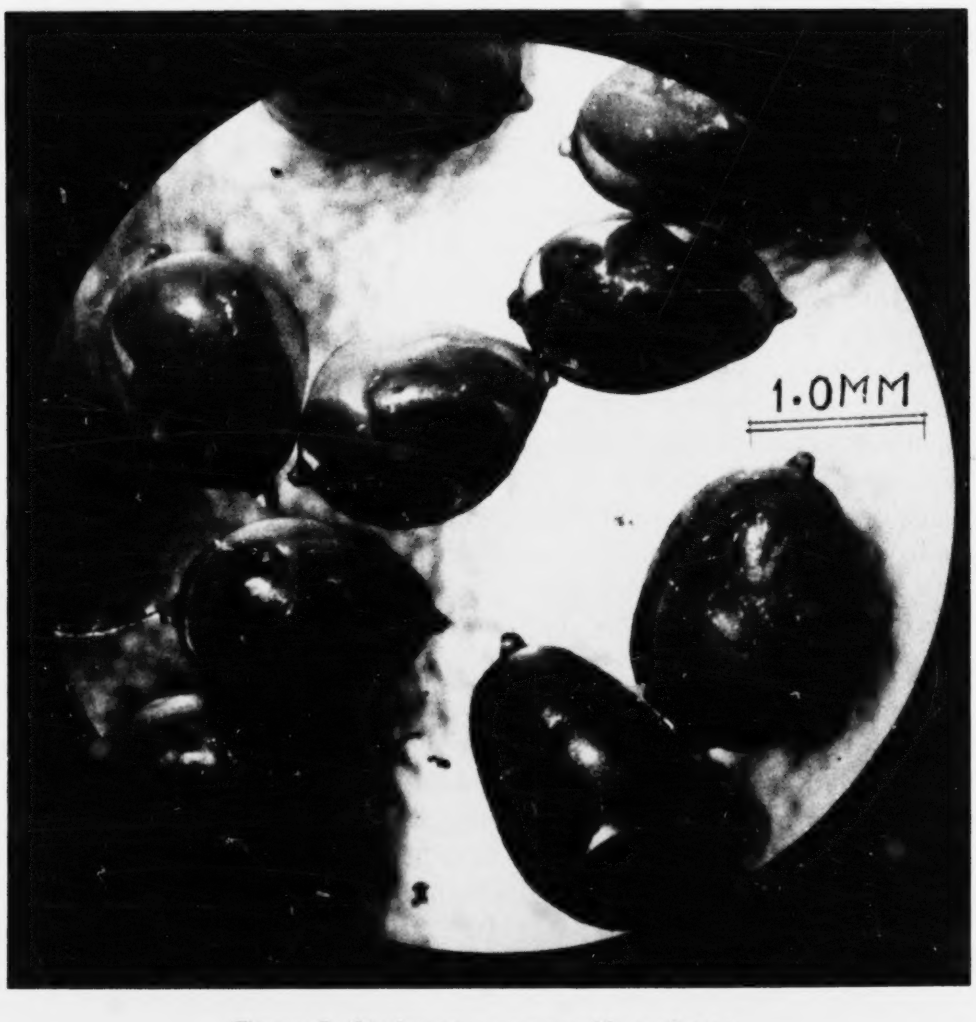


Figure 3. Sludgeworm eggs with embryos.

The zone of recovery is essentially the downstream transition zone between the zone of active decomposition and an environment that is unaffected by pollution. This zone features a gradual cleaning up of the environment, a reduction in those features that form adverse conditions for aquatic life, an increase in organism species, and a gradual decrease in organism population because of decreased food supply and the presence of some of the predators that are less sensitive individually to pollutional affects.

Because of some variation in response among species to conditions of existance within the environment, and because of inherent difficulties in aquatic invertebrate taxonomy, the ecological evaluation of the total organism community is the acceptable approach in water pollution control investigations. At the present time, investigators tend to place organism in broad groups according to the general group response to pollutants in the environment. As we are able to advance our knowledge and determine more specifically the water quality requirements of identifiable species, the use of specific organism indicators may become more prevalent in biological interpretation. The general group known as "sludge-worms," for example, is found in both the unpolluted, as well as the organically polluted environment. Its value as a group lies in the fact that the numbers of individuals within the group is exceedingly low in unpolluted water, whereas in the organically polluted environment its numbers may be very high. Examples of organisms that may inhabit both the unpolluted and polluted environments are presented in table 1.

The converse of the effects of pollution on organisms is the effects of organisms on pollutants. Organic wastes, especially, supply food which in turn produces an abundance of a few types of organisms greater than that produced in an unpolluted environment. In consuming organic wastes, the organisms stabilize the waste in a given number of feet or miles of horizontal stream in a manner similar to that in a vertical trickling filter that is designed especially for maximum stabilizing efficiency by the organisms.

Purdy (1930) found long ago that sludgeworms eat continuously. Observations during 21 out of 24 hours showed no perceptible decrease in the foraging activity. Evacuation of a string of fecal pellets about 68 inches in length in a 24-hour period was recorded for each worm. An incubation of 24 hours showed an oxygen demand of 2.8 mg./l. by these pellets, whereas the original mud beneath the surface showed a demand of 6.7 mg./l. Purdy's conclusion was that the large surface area of fecal pellets exposed to the flowing water possessed a far greater purification

Table 1. Organism Associations

Clean water association		Polluted water association	
Algae	*Cladophora* (green) *Ulothrix* (green) *Navicula* (diatom)	Iron Bacteria	*Sphaerotilus*
Protozoa	*Trachelomonas*	Fungi	*Leptomitus*
Insects	Plecoptera (stoneflies in general) Negaloptera (hellgrammites, alderflies, and fishflies in general) Trichoptera (caddisflies in general) Ephemeroptera (mayflies in general) Elmidae (riffle beetles in general)	Algae	*Chlorella* (green) *Chlamydomonas* (green) *Oscillatoria* (blue- green) *Phormidium* (bluegreen) *Stigeoclonium* (green)
Clams	Unionidae (pearl button)	Protozoa	*Carchesium* (stalked colonial ciliate) *Colpidium* (non-colonial ciliate)
Fish*	*Etheostoma* (darter) *Notropis* (shiner) *Chrosomus* (dace)	Segmented Worms	*Tubifex* (sludgeworms) *Limnodrilus* (sludge-worms)
		Leeches	*Helobdella stagnalis*
		Insects	*Culex pipiens* (mosquito) *Chironomus* (*-Tendipes*) *plumosus* (bloodworms) *Tubifera* (*Eristalis tenax*) (rat-tailed maggot)
		Snail	*Physa integra*
		Clam	*Sphaerium* (fingernail)
		Fish*	*Cyprinus carpio* (carp)

* Names from: American Fisheries Society Special Publication No. 2, "A List of Common and Scientific Names of Fishes from the United States and Canada" (Second Edition) Ann Arbor, Mich. (1960), 102 pp.

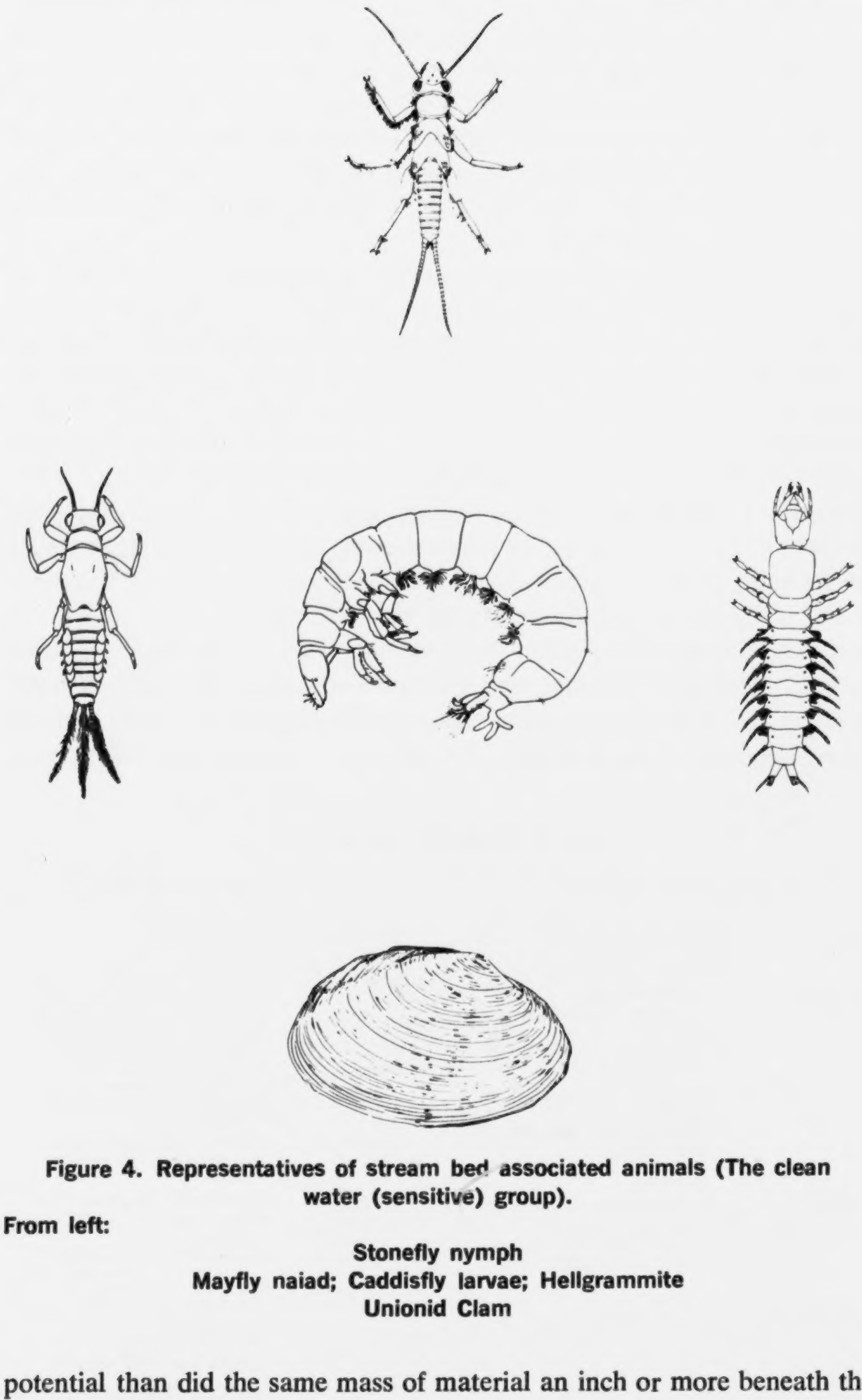


Figure 4. Representatives of stream bed associated animals (The clean water (sensitive) group).

From left:

Stonefly nymph
Mayfly naiad; Caddisfly larvae; Hellgrammite
Unionid Clam

potential than did the same mass of material an inch or more beneath the sludge-water interface.

As organic wastes become more stabilized, other organism types predominate within the aquatic animal community. Midge larvae have been

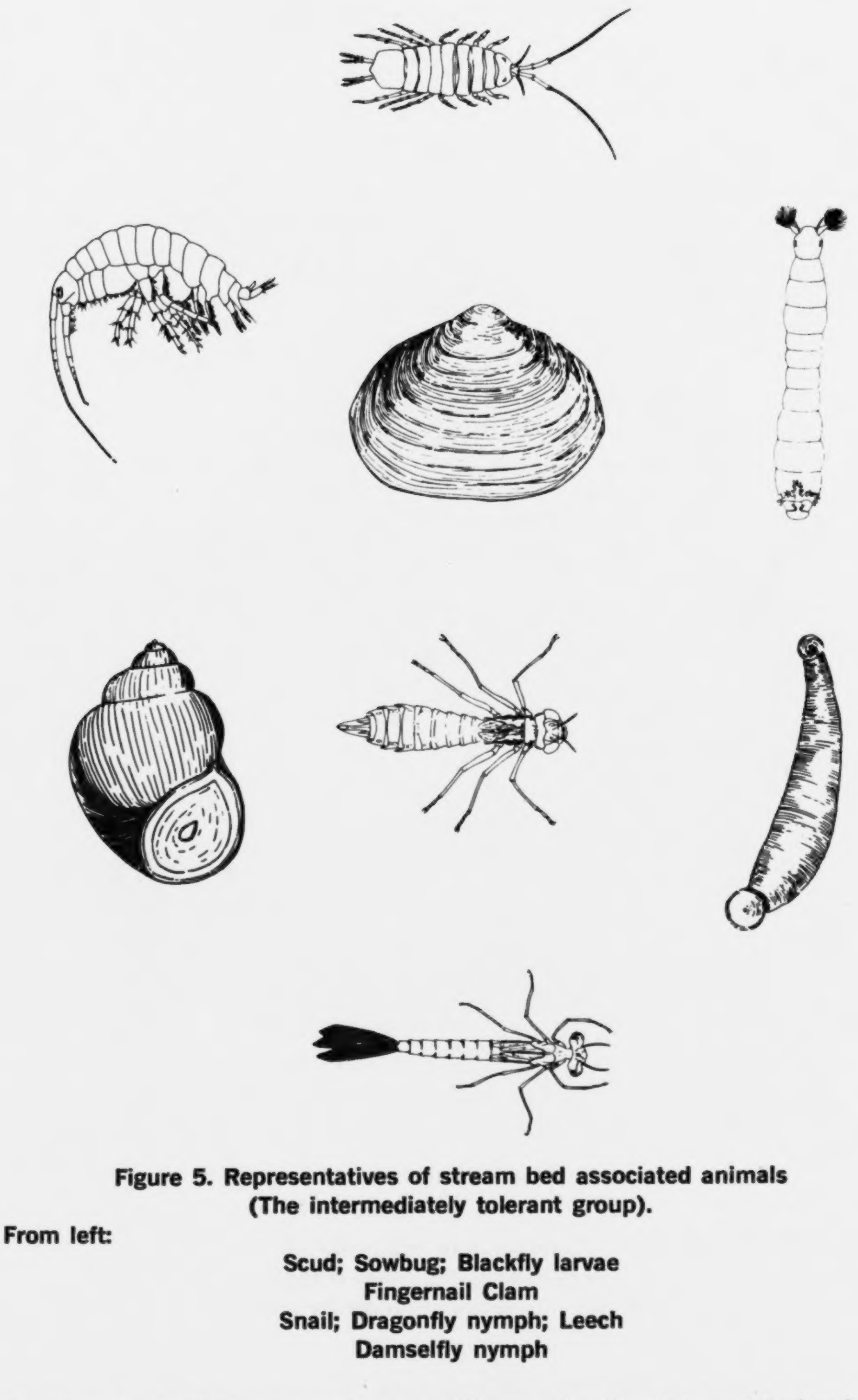


Figure 5. Representatives of stream bed associated animals (The intermediately tolerant group).

From left:

Scud; Sowbug; Blackfly larvae
Fingernail Clam
Snail; Dragonfly nymph; Leech
Damselfly nymph

found to "paint" the stream bed a brilliant red with their undulating bodies. Caddisfly larval populations greater than 1,000 per square foot of stream bed or mayfly nymphs numbering more than 300 per square foot have been found on several occasions.

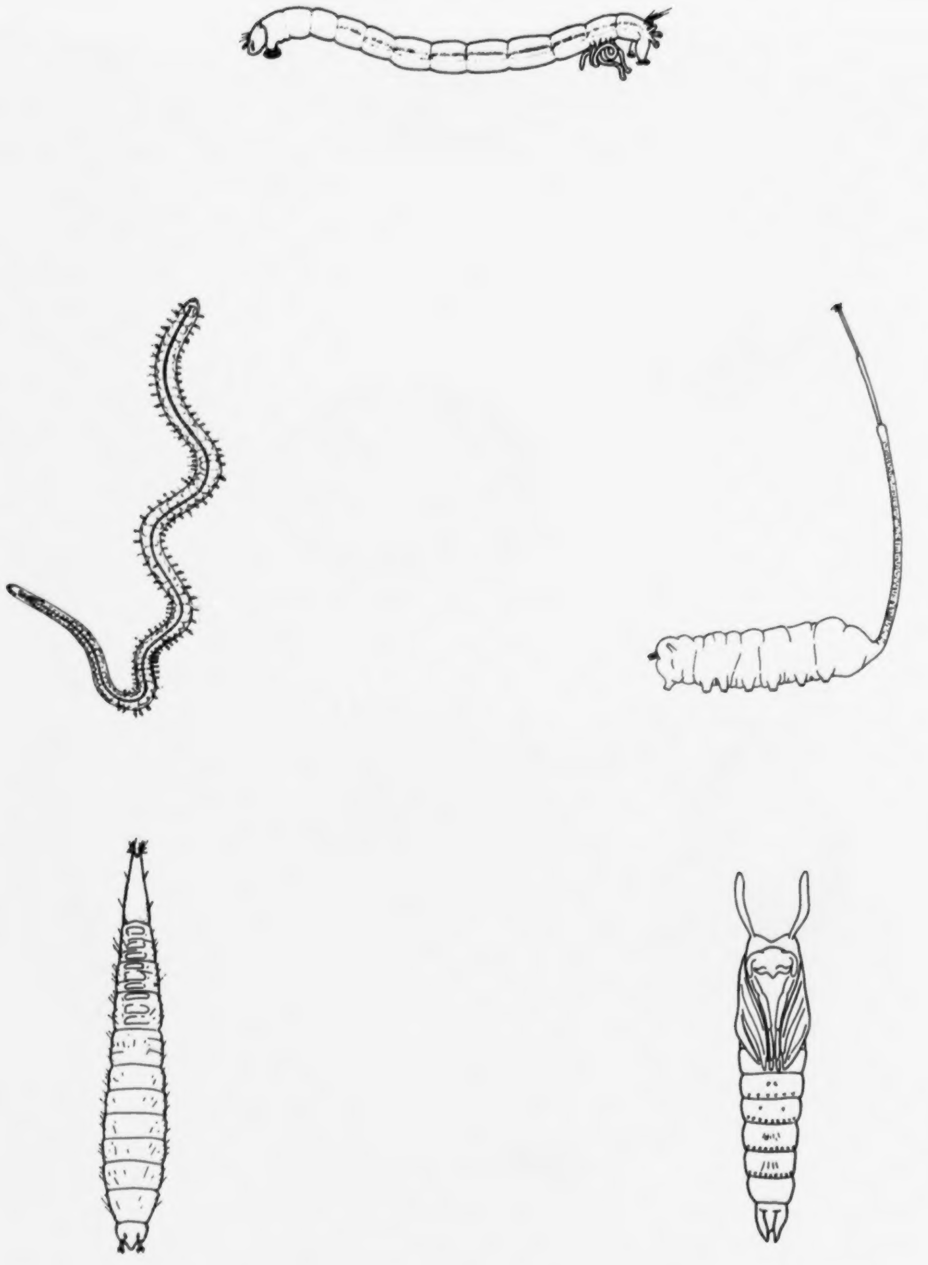


Figure 6. Representatives of stream bed associated animals (The very tolerant group).

From left:
Bloodworm or midge larvae
Sludgeworm; Rat-tailed maggot
Sewage fly larvae; Sewage fly pupae

The estuarine and marine environments have not been studied as extensively as the fresh-water habitats. Reish (1960) cited Wilhelm (1916) to the effect that the polychaete *Capitella capitata* (Fabricius) plays a role in marine waters similar to that of the oligochaete, *Tubifex,* in fresh water.

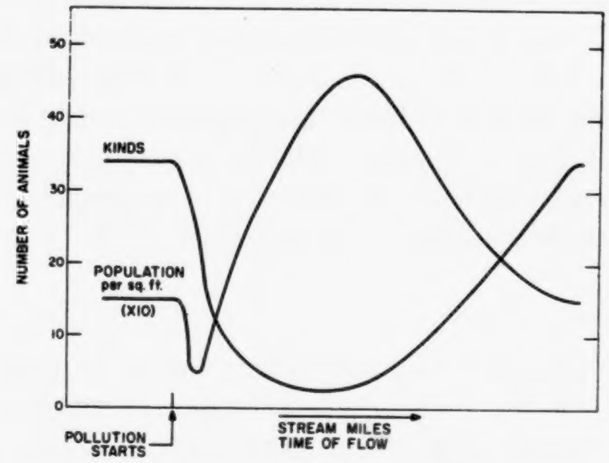
Filice (1954) and Reish (1960) found three benthic zones surrounding a major pollutional discharge: one essentially lacking in animals, an intermediate zone having a diminished fauna, and an outer zone unaffected by the discharge. Filice (1959) found the crab *Rhithropanopeus harrisii* (Gould) present more abundantly than expected near industrial outfalls: this crab and *Capitella capitata* (Fabricius) were present in large numbers near domestic outfalls. Hedgpeth (1957) reviewed the biological aspects of the estuarine and marine environments.

Inorganic Silts

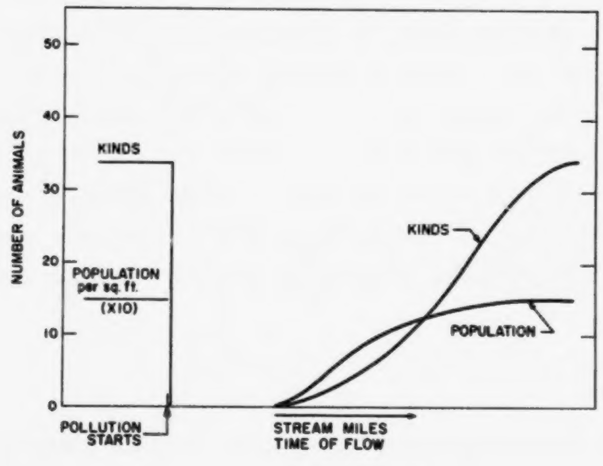
The general effect on the aquatic environment of inorganic silts is to reduce severely both the kinds of organisms present and their populations. As particulate matter settles to the bottom it can blanket the substrate and form undesirable physical environments for organisms that would normally occupy such a habitat. Erosion silts alter aquatic environments chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom and destroying living spaces, and by retaining organic materials and other substances that can create unfavorable conditions. Developing eggs of fish and other organisms may be smothered by deposits of silt; fish feeding may be hampered. Direct injury to fully developed fish, however, by nontoxic suspended matter occurs only when concentrations are higher than those commonly found in natural water or associated with pollution.

Toxic Metals

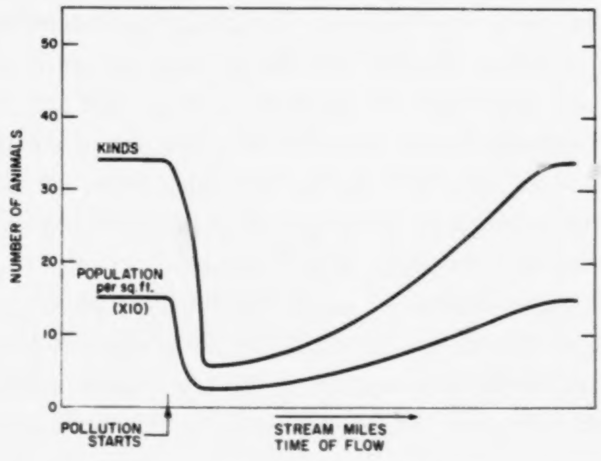
Wastes containing concentrations of heavy metals, either individually or in combination, may be toxic to aquatic organisms and, thus, have a severe impact on the water community. A severely toxic substance will eliminate aquatic biota until dilution, dissipation, or volatilization reduces the concentration below the toxic threshold. Less generally toxic materials will reduce the aquatic biota, except those species that are able to tolerate the observed concentration of the toxicant. Because toxic materials offer no increased food supply, such as has been discussed for organic wastes, there is no sharp increase in the population of those organisms that may tolerate a specific concentration. The bioassay is an important tool in the investigation of these wastes, because the results from such a study indicate the degree of hazard to aquatic life of particular discharges; interpretations and recommendations can be made from these studies concerning the level of discharge that can be tolerated by the receiving aquatic community.



ORGANIC (NON-TOXIC) POLLUTION



TOXIC POLLUTION



SILT (INERT) POLLUTION

Figure 7. Pollutional Effects on Animals

3

WATER QUALITY CONSTITUENTS

*Temperature**

TEMPERATURE is a prime regulator of natural processes within the water environment. It governs physiological functions in organisms and, acting directly or indirectly in combination with other water quality constituents, it affects aquatic life with each change. These effects include chemical reaction rates, enzymatic functions, molecular movements, molecular exchanges between membranes, etc., within and between the physiological systems and organs of an animal. Because of the complex interactions involved, and often because of the lack of specific knowledge or facts, temperature effects as they pertain to an animal or plant are most efficiently assessed on the basis of net influence on the organism. Depending on the extent of environmental temperature change, organisms can be activated, depressed, restricted, or killed.

Temperature determines those aquatic species that may be present; it controls spawning and the hatching of young, regulates their activity and stimulates or suppresses their growth and development; it can attract and kill when the water becomes heated or chilled too suddenly. Colder water generally suppresses development; warmer water generally accelerates activity.

Temperature regulates molecular movement and thus largely determines the rate of metabolism and activity of all organisms, both those with a relatively constant body temperature and those whose body temperature is identical to, or follows closely, the environmental temperature. Because of its capacity to determine metabolic rate, temperature may be the most important single environmental entity to life and life processes.

Variations in temperature of streams, lakes, estuaries, and oceans are normal results of climatic and geologic phenomena. Waters that support some form of aquatic life other than bacteria or viruses range in temperature from 26.6° F. in polar sea waters to 185° F. in thermal springs. Most aquatic organisms tolerate only those temperature changes that occur within a narrow range to which they are adapted, whether it be high, intermediate, or low on this temperature scale.

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* Taken from comments presented by Mackenthun, K. M. and L. E. Keup before the 1969 meeting of the American Power Conference sponsored by the Illinois Institute of Technology, Chicago, Ill.

Within the same species, the effects of a given temperature may differ in separate populations, in various life cycle stages, or between the sexes, and such effects may depend on the temperature history of the individual tested, as well as on present or past effects of other environmental factors.

Freshwater has the greatest density at 38° F.; higher and lower temperatures result in waters with lower density. Seasonally induced temperature changes are greatest in the midlatitudes.

In lakes, insolation warms the surface waters in spring, reducing their densities compared to the deeper waters until eventually the density differences are sufficient to prevent the wind from mixing the body of water; thermal stratification then occurs. The warm upper layer (epilimnion) is well mixed to a depth determined by wave and other wind induced currents. The cool bottom waters (hypolimnion) become stagnant except for minor currents confined to this strata. A strata of sudden temperature changes (thermocline) separates these regions. In autumn, the lake radiates heat, surface temperatures decrease, surface water density increases, and water viscosity increases. Soon the wind, aided by reduced density differences between water layers, mixes the surface with the bottom waters resulting in a homogenous water mass. Depending on altitude and local climatic conditions, the lake continues to mix until the following spring in latitudes of less than about 40°. In latitudes north of about 40°, winter surface water temperatures are less than 38° F. and these are superimposed over the water mass until they are cooled to freezing. An ice cover eliminates wind induced mixing and stagnation occurs.

Thermal stratification in reservoirs may assume many patterns depending on geographical location, climatological conditions, depth, surface area, and type of dam structure, penstock locations, and hydropower use. In general, large, deep impoundments will cool downstream waters in the summer and warm them in winter when withdrawal ports are deep; shallow, unstratified impoundments with large surface areas will warm downstream waters in the summer; water drawn from the surface of a reservoir will warm downstream waters; a reduction in normal flow downstream from an impoundment will cause marked warming in summer; and "run-of-river" impoundments, where the surface area has not been increased markedly over the normal river area, will produce only small changes in downstream water temperatures.

In the deep, stagnant, summer bottom waters, as well as in ice covered waters, atmospheric reaeration is absent and oxygen from photosynthesis by plants is limited. Decomposing organisms (especially those settling to the bottom waters in summer) remove oxygen from the water and the gaseous byproducts of decomposition are trapped. Undesirable soluble phosphorus, carbon dioxide, iron, and manganese concentrations increase in these stagnant waters. Designed thermal discharges can reduce some of these problems. Ice cover can be limited, thus allowing wind and thermally induced currents to reduce winter stagnation. A deepwater summer discharge could warm hypolimnetic waters to decrease density and permit total water mass mixing where a cold water fishery would not be damaged by such action.

Stratification may occur in streams receiving heated effluents. There are three recognized forms of stream stratification: overflow, interflow, and underflow; the forms are determined by the relationship between the density of the influent and the density of the stream water.

Surface freshwaters in the United States vary from 32° to over 100° F. according to the latitude, altitude, season, time of day, duration of flow, depth, and many other variables. Agents affecting natural water temperature are so numerous that no two water bodies, even in the same latitude, are likely to have the same thermal characteristics. Fish and other aquatic life occurring naturally in each body of water are those that have become adapted to the temperature conditions existing there. The interrelationships of species, length of daylight and water temperature are so intimate that even a small change in temperature may have far-reaching effects. An insect nymph in an artifically warmed stream, for example, might emerge for its mating flight too early in the spring and be immobilized by the cold air temperature, or a fish might hatch too early in the spring to find its natural food organisms because the food chain depends ultimately on plants, and these in turn, upon length of daylight, as well as temperature. The inhabitants of a water body that seldom becomes warmer than 70° F. are placed under stress, if not killed outright, by 90° F. water. Even at 75° to 80° F., they may be unable to compete successfully with organisms for which 75° to 80° F. is favorable. Similarly, the inhabitants of warmer waters are at a competitive disadvantage in cool water.

An animal's occurrence in a given habitat does not mean that it can tolerate the seasonal temperature extremes of that habitat at one time. The habitat must be cooled gradually in the fall if the animal is to become acclimatized to the cold water of winter, and warmed gradually in the spring if it is to withstand summer heat.

Some organisms might endure a temperature of 92° to 95° F. for a few hours, but not for days. Gradual change of water temperature with the season is important for other reasons: an increasing or decreasing temperature often "triggers" spawning, metamorphosis, and migration. The eggs of some freshwater organisms must be chilled before they will hatch properly.

The temperature range tolerated by many species is narrow during very early development; it increases somewhat during maturity, and decreases

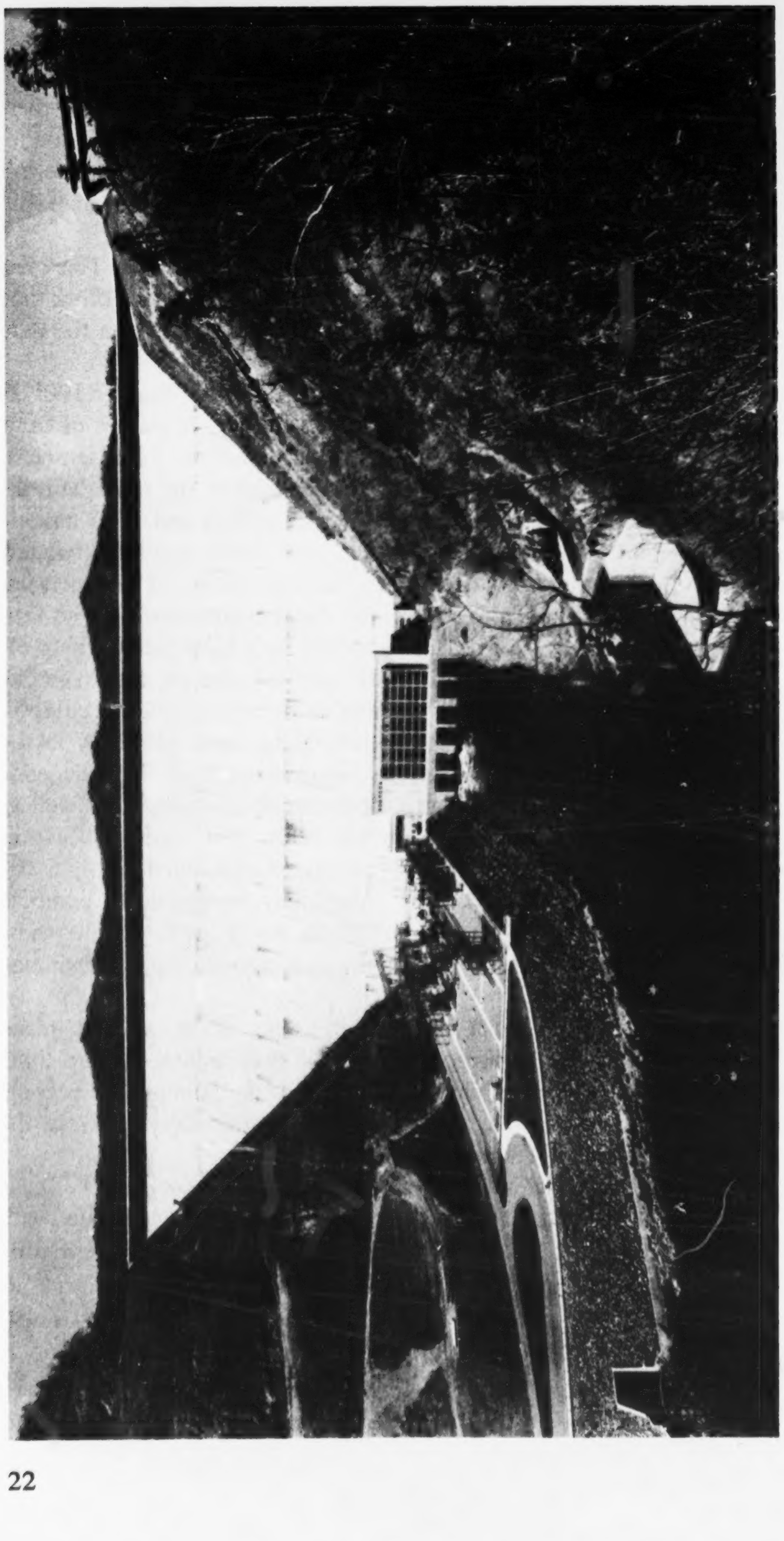

Figure 8. Fontana Project, Tennessee Valley Authority

again in the old adult. Similarly, the tolerable temperature range is often more restrictive during the reproductive period that at other times during maturity. Upper lethal temperatures may be lower for animals from cold water than for closely related species from warm water. Many motile organisms such as fish, some zooplankton, certain algae, and some associated animals can avoid critical temperatures by vertical and horizontal migration into more suitable areas. However, some organisms may be attracted to areas with critical temperatures, and, upon arrival, succumb.

Changes in fish populations can result from many types of artificial cooling and heating of natural waters. These changes result from the discharge of condenser cooling water from thermal electric generating plants, industrial waste cooling waters, and other heated effluents, and irrigation waters. Streams are warmed also by the sun when the shade from stream bank trees and other vegetation is eliminated. The discharge of cold water from stratified impoundments may provide an ideal habitat for trout and other cold water fish, when sufficient dissolved oxygen is present, but not for the warm water fish that inhabited the stream before impoundment.

For every 18° F. increase in temperature, the chemical reaction rate is approximately doubled in an organism or in an environment. Life processes in the water are accelerated with temperature increases and slowed as the water cools.

The solubility of gases, including oxygen, in water varies inversely with temperature. In fresh water, the solubility of atmospheric oxygen is decreased by about 55 percent as the temperature rises from 32° to 104° F. under 1 atmosphere of pressure (760 mm. Hg.). Because all desirable living things are dependent on oxygen in one form or another to maintain the life processes that produce energy for growth and reproduction, dissolved oxygen is of imposing significance in the aquatic environment.

When organism metabolism increases because of higher temperatures, organism development is speeded, and more dissolved oxygen is required to maintain existence. But, bacterial action in the natural purification process to break down organic materials is also accelerated with increased temperatures, thus reducing the oxygen that could be available in the warmer water. When organisms use larger amounts of oxygen, and when oxygen has been reduced by temperature action and interaction, organisms may perish. Life stages that are especially vulnerable are the eggs and larvae. At higher temperatures, phytoplankton have been found to need greater amounts of certain growth factors such as vitamin B_{12}. Between 96.8° and 98.2° F., for example, the vitamin requirement has been found to increase over 300 times for some species.

Fish and other motile organisms seek a preferred temperature at which they can best survive, which is several degrees below a temperature that is lethal. Larger individuals tend to move out of areas that are too hot, but larvae and juveniles cannot often move fast enough to avoid a sudden temperature increase. Large fish and fish in schools avoid heated areas in summer but may be attracted to such areas in winter. This phenomenon may result in good fishing during the cooler months, but an absence of this sport at other times.

Reproduction cycles may be changed significantly by increased temperature because this function takes place under restricted temperature ranges. Spawning may not occur at all because temperatures are too high. Thus, a fish population may exist in a heated area only by continued immigration. Disregarding the decreased reproductive potential, water temperatures need not reach lethal levels to wipe out a species. Temperatures that favor competitors, predators, parasites, and disease can destroy a species at levels far below those that are lethal.

Fish food organisms are altered severely when temperatures approach or exceed 90° F. Predominant algal species change, primary production is decreased, and bottom associated organisms may be depleted or altered drastically in numbers and distribution. Increased water temperatures may cause aquatic plant nuisances when other environmental factors are favorable.

Synergistic actions of pollutants are more severe at higher water temperatures. Given amounts of domestic sewage, refinery wastes, oils, tars, insecticides, detergents, and fertilizers more rapidly deplete oxygen in water at higher temperatures, and the respective toxicities are likewise increased.

The National Technical Advisory Committee on Water Quality Criteria (Anon., 1968), composed in part of the nation's leading fishery experts, recommended that to maintain a well-rounded population of warm water fishes, heat added to a freshwater stream not exceed that which would raise the water temperature more then 5° F. at the expected minimum daily flow for the month involved. In lakes, the temperature of the upper waters should not be raised more than 3° F. above that which existed before heat was added. The increase should be based on the monthly average of the maximum daily temperatures. Temperature should be measured in those areas where important organisms are most likely to be affected adversely.

The Committee recommended provisional maximum temperatures as compatible with the well-being of various fish species and their associated biota as follows:

93° F.: Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, and gizzard shad.
90° F.: Growth of largemouth bass, drum, bluegill, and crappie.
84° F.: Growth of pike, perch, walleye, smallmouth bass, and sauger.
80° F.: Spawning and egg development of catfish, buffalo, threadfin shad, and gizzard shad.
75° F.: Spawning and egg development of largemouth bass, white and yellow bass and spotted bass.

68° F.: Growth or migration routes of salmonids and for egg development of perch and smallmouth bass.

55° F.: Spawning and egg development of salmon and trout (other than lake trout).

48° F.: Spawning and egg development of lake trout, walleye, northern pike, and sauger.

Because of the large number of trout and salmon waters that have been destroyed, made marginal or nonproductive, remaining trout and salmon waters must be protected if these resources are to be preserved. The Committee further recommended that inland trout streams, headwaters of salmon streams, trout and salmon lakes and the deeper waters of lakes that contain salmonids not be warmed. No heated effluents should be discharged in the vicinity of spawning areas.

Little work has been done regarding thermal addition effects in subtropical estuarine ecosystems. In the subtropical environment, optimum temperatures for many forms are only a few degrees lower than maximum lethal temperatures. Organisms may be existing under stress with naturally occurring summer temperatures. Great care should be exercised to prevent harmful temperature increases.

In general, marine water temperatures do not change as rapidly or range as widely as those of freshwaters. Marine and estuarine fishes, therefore, are less tolerant of temperature variation. Although this limited tolerance is greater in the estuarine than in the open water marine species, temperature changes are more important to those fishes in estuaries and bays than to those in open marine areas.

Marine surf-zone discharge from large-scale coastal power plants may be expected to significantly alter the shore environment for species of invertebrates and fish that are commonly found there.

Some investigators have becomed alarmed over the loss in organisms contained in the water pumped across condensers and through a generating plant. These are subject to thermal shock, physical damage, and perhaps commercial additives. These organisms include phytoplankton, crustaceans, zooplankton, and shellfish larvae, such as clams and oysters that have stages of drift in the water column for a few weeks before they settle to the bottom. Studies have shown a 95 percent mortality of these organisms when they are subjected to the rise in temperature in crossing the condenser.

Available data indicate that commercial and key food-chain estuarine animals cannot tolerate temperatures greater than approximately 90° F. regardless of the temperature to which they have been acclimated. Thus, natural peak summer water temperatures in a subtropical or tropical estuary may be near the tolerance threshold for a number of desirable marine organisms.

In subtropical waters, organisms that find the environment undesirable are not replaced by organisms of greater temperature tolerance, as so often happens in northern latitudes.

The National Technical Advisory Committee on Water Quality Criteria, in reporting to the Secretary of the Interior, recommended that the discharge of any heated materials into coastal waters be closely managed. This Committee stipulated that any rise owing to such discharges should be restricted to 1.5° F. during the critical summer months, outside of established mixing zones. To make water quality standards more meaningful, mixing zones must have definition. The National Technical Advisory Committee suggested only that adequate passageways be provided at all times for the movement or drift of organisms, and that mixing areas must not be used for, or considered as, a substitute for waste treatment, or as an extension of, or substitute for, a waste treatment facility.

Dissolved Oxygen

Dissolved oxygen (D.O.) is a water quality constituent that, in appropriate concentrations, is essential not only to keep organisms living but also to sustain species reproduction, vigor, and the development of populations. Organisms undergo stress at reduced D.O. concentrations that make them less competitive to sustain their species within the aquatic environment. For example, D.O. concentrations around 3 milligrams per liter (mg/l) or less have been shown to interfere with fish populations through delayed hatching of eggs (Silver et al., 1963), reduced size and vigor of embryos (Silver et al., 1963; Van Horn and Balch, 1957), production of monstrosities in young (Alderdice et al., 1958), interference with food digestion and acceleration of blood clotting (Bouck & Ball, 1965), decreased tolerance to certain toxicants (Cairns and Scheier, 1957), reduced food efficiency and growth rate (Chiba, 1966; Herrman et al., 1962), and reduced maximum sustained swimming speed (Davis et al., 1963).

Oxygen enters the water by absorption directly from the atmosphere or by plant photosynthesis, and is removed by respiration of organisms and by decomposition. That derived from the atmosphere may be by direct diffusion or by surface water agitation by wind and waves, which may also release dissolved oxygen under conditions of supersaturation.

In photosynthesis, aquatic plants utilize carbon dioxide and liberate dissolved and free-gaseous oxygen at times of supersaturation. Since energy is required in the form of light, photosynthesis is limited to the photic zone were light is sufficient to facilitate this process. According to Dice (1952), ". . . the ultimate limit of productivity of a given ecosystem is governed by the total effective solar energy falling annually on the area, by the efficiency with which the plants in the ecosystem are able to transform this energy into organic compounds, and by those physical factors of the environment which affect the rate of photosynthesis." Verduin (1956) summarized the literature on primary production in lakes; based on computations of photosynthetic oxygen production, he found that the yields of several lakes were mostly between 42 and 57 pounds of dissolved oxygen per acre per day. A year-round study under completely natural conditions in western Lake Erie showed winter yields of about 11 pounds of dissolved oxygen production per acre per day, and summer maxima of about 85 pounds per acre per day. The annual oxygen production curve closely followed the solar radiation curve. The net oxygen production rate for East Okoboji Lake in Iowa, a producer of large plankton populations, was 79 pounds per acre per day, with production largely confined to the first 2 meters (Weber, 1958). Whipple et al. (1948) noted that supersaturation in the upper waters is not cumulative to a great extent because circulation is maintained by wind action and convection currents both of which promote contact of the water and the air with a consequent loss of oxygen. Higher saturation is frequently found in the upper region of the thermocline in infertile oligotrophic lakes. Wind action seldom disturbs the waters of this zone, convection currents are absent, and diffusion is a slow process. Plants find an abundant supply of carbon dioxide and sufficient light in this area to stimulate photosynthesis, resulting in supersaturation values that may exceed 300 percent.

During respiration and decomposition, animals and plants consume dissolved oxygen and liberate carbon dioxide at all depths where they occur. Because excreted and secreted products and dead animals and plants sink, most of the decomposition takes place in the hypolimnion; thus, during lake stratification there is a gradual decrease of dissolved oxygen in this zone. After the dissolved oxygen is depleted, anaerobic decomposition continues with evolution of methane and hydrogen sulfide.

In the epilimnion, during thermal stratification, dissolved oxygen is usually abundant and is supplied by atmospheric aeration and photosynthesis. Phytoplankton are plentiful in fertile lakes and are responsible for most of the photosynthetic oxygen. The thermocline is a transition zone from the standpoint of dissolved oxygen, as well as temperature. The water rapidly cools in this region, incident light is much reduced, and photosynthesis is usually decreased; if sufficient dissolved oxygen is present, some cold water fish abound. As dead organisms that sink into the hypolimnion decompose, oxygen is utilized; consequently, the hypolimnion in fertile lakes may become devoid of dissolved oxygen following a spring overturn, and this zone may be unavailable to fish and most benthic invertebrates at this time. During the two brief periods in spring and fall when lake water circulates, temperature and dissolved oxygen are the same from top to bottom and fish can use the entire water depth.

The National Technical Advisory Committee (Anon., 1968) recommended that D.O. concentrations be above 5 mg/l assuming normal seasonal and daily variations for a diversified warm water biota. The Committee stated that under extreme conditions concentrations may range between 5 and 4 mg/l for short periods during any 24-hour period, providing that the water quality is favorable in all other respects. For cold water biota, it is desirable that D.O. concentrations be at or near saturation especially in spawning areas. D.O. levels in the hypolimnion of lakes should not be lowered below 6 mg/l at any time because of the addition of oxygen demanding wastes. The Committee further specified that D.O. concentrations in surface coastal waters should be greater than 5.0 mg/l, except when upwellings and other phenomena may cause this value to be depressed. D.O. concentrations in estuaries and tidal tributaries should not be less than 4.0 mg/l at any time or place, except in naturally dystrophic waters or where natural conditions cause D.O. to be depressed.

pH

The world's literature on pH published prior to about 1950 has been critically evaluated by Doudoroff and Katz (1950). They concluded that ". . . under otherwise favorable conditions, pH values above 5.0 and ranging upward to pH 9.0, at least, are not lethal for most fully developed freshwater fishes. Much more extreme pH values, perhaps below 4.0 and well above 10.0, also can be tolerated indefinitely by resistant species. However, regardless of the nature of acid or alkaline wastes responsible, such extreme conditions, associated with industrial pollution, are evidently undesirable and hazardous for fish life in waters which are not naturally so acid or alkaline."

Lloyd (1968) summarized the conclusions of the European Inland Fisheries Advisory Commission, Food and Agricultural Organization of the United Nations, with the statement:

> "There is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather there is a gradual deterioration as the pH values are further removed from the normal range. The pH range which is not directly lethal to fish is 5–9; however, the toxicity of several common pollutants is markedly affected by pH changes within this range; and increasing acidity or alkalinity may make these poisons more toxic. Also, an acid discharge may liberate sufficient carbon dioxide from bicarbonate in the water either to be directly toxic, or to cause the pH range 5–6 to become lethal.
>
> "Below a pH value of 5.0 fish mortalities may be expected, although some species may become acclimated to values as low as 3.7. However, the productivity of the aquatic ecosystem is considerably reduced below a pH value of 5.0, so that the yield from a fishery would also become less. Some acid waters may contain precipitated ferric hydroxide which may also act as a lethal factor."

The National Technical Advisory Committee (Anon., 1968) recommended for fish and other aquatic life that:

(1) No highly dissociated materials should be added in quantities sufficient to lower the pH below 6.0 or to raise the pH above 9.0.

(2) To protect the carbonate system and thus the productivity of the water, acid should not be added in sufficient quantity to lower the total alkalinity to less than 20 mg/l.

(3) The addition of weakly dissociated acids and alkalies should be regulated in terms of their own toxicities as established by bioassay procedures.

Neel et al. (1961), in studying raw-sewage stabilization ponds, found that pH values above 8.0 are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition; pH levels below 8.0 indicate failure of photosynthesis to utilize completely the amounts of carbon dioxide so produced. "In general practice, pH values above 8.0 are assumed to denote the presence of carbonate; a level of 8.0 indicates bicarbonate alone; and values below 8.0 show the occurrence of free carbon dioxide. Carbon dioxide, usually produced by decomposition and respiration, will react with any carbonate present to form bicarbonate and water. Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate when no free CO_2 exists. Carbonates of calcium and magnesium are but weakly soluble and quantities of them leave solution. Decomposition and/or respiration thus tends to reduce pH and increase bicarbonates, whereas the tendency of photosynthesis is to raise pH and reduce bicarbonate" (Neel et al., 1963).

Light

Rooted, suspended, and floating aquatic plants require light for photosynthesis. Light penetration into waters is exceedingly variable in different lakes. Clarke (1939) pointed out that the diminution of the intensity of light in its passage through water follows a definite mathematical formula. The relationship between the depth of water and the amount of light penetrating to that depth can be plotted as a straight line on semilogarithmic paper. Even the clearest waters impede the passage of light to some extent; light passed through 100 meters of distilled water is reduced to 1 or 2 percent of its incident value.

The principal factors affecting the depth of light penetration in natural waters include suspended microscopic plants and animals, suspended mineral particles such as mineral silt, stains that impart a color, detergent foams, dense mats of floating and suspended debris or a combination of these. The region in which light intensity is adequate for photosynthesis is often referred to as the trophogenic zone, the layer that encompasses 99 percent of the incident light. The depth of the trophogenic zone may vary from less than 5 to greater than 90 feet.

The length of daylight in water varies inversely with the depth of the water. The seasonal variation in the intensity of solar radiation influences the potential rate of photosynthesis. In winter the presence of ice with an over layer of snow further limits the amount of relatively poor incident light energy that reaches the water. The work of Birge, reported by Neess and Bunge (1957), indicates that the absorptive quality of clear ice is very similar to that of water, although the addition of air bubbles or particulate matter reduces the transmission of light. Snow further reduces light penetration through ice. Greenbank (1945) found 84 percent light transmission through 7½ inches of very clear ice, and 22 percent through 7½ inches of very cloudy ice. A 1-inch snow cover permitted only 7 percent light transmission through the ice and snow; 2 inches of snow permitted only 1 percent light transmission. Bartsch and Allum (1957), studying sewage stabilization ponds, found that in the absence of snow 20 to 55 percent of the incident light passed through 10 to 12 inches of ice, whereas, with a 1- to 3- inch snow cover 93 to 99 percent of the incident light was absorbed by ice and snow, when the ice was 1 to 2 feet thick. Mackenthun and McNabb (1961) found less than 1 percent of light passing through 16 inches of ice covered by 2 inches of snow.

Beeton (1958) made 57 paired photometer and Secchi disc measurements at 18 stations in Saginaw Bay in Lake Huron. He found that the average percentage transmission of surface light intensity, at the Secchi disc depth, was 14.7 percent. Verduin (1956) made simultaneous determinations with the Secchi disc and submarine photometer during August, 1955, on Lake Erie. The Secchi disc readings in meters were plotted against the depth associated with 1 percent of the surface light. A line drawn by inspection through the scatter diagram, suggests that an approximate estimation of the depth of the euphotic zone can be obtained by multiplying the Secchi disc readings by 5. Riley (1941) used a factor of 3. Verduin (1956) computed a factor of 2.5 using the data of Bursche (1955). Rawson (1950) listed a factor of 4.3 for a Secchi disc reading of about 1 meter.

Tyler (1968), after extensive experimentation, concluded that Secchi disc readings could be used to plot the depth of the euphotic zone for a particular body of water provided that calibrations had been made against a photometer for that particular water. Tyler further concluded that if modern instruments were available for measuring precise light penetration, that it would probably be better not to undertake such a calibration.

The maximum Secchi disc reading reported for Lake Tahoe, California-Nevada, was 136 feet at one station on April 4, 1962 (McGauhey et al., 1963). A minimum Secchi disc reading of 49 feet was recorded in Emerald Bay of Lake Tahoe on May 21, 1962. In contrast, the Secchi disc disappeared in 3 feet in Lake Sebasticook, Maine, during a July, 1965, study. In areas with less dense algal growths, the readings were increased to 8 feet. Beeton (1965) records the average Secchi disc depth for Lake Superior as 32.5 feet; Lake Michigan, 19.6 feet; and Lake Erie, 14.6 feet.

Flow

The velocity of water movement is extremely important to aquatic organisms in a number of ways including the transport of nutrients and organic food past those organisms attached to stationary surfaces; the transport of plankton and benthos as drift, which in turn serve as food for higher organisms; and the addition of oxygen to the water through surface aeration. Silts are moved downstream and sediments may be transported as bed load. These in turn are often associated with major nutrients, such as nitrogen and phosphorus, which may be released at some point downstream from their introduction.

The determination of flow is necessary to compute pounds of materials passing a given point. Computations are often made on pounds of nitrogen, phosphorus, or other elements of concern, on amounts of plankton and benthos as drift, on amounts of pollutants, such as wool, fibers, or other microscopical identifiable materials that may be associated with a point source.

Flow determines those species of stream bed organisms that may be present in a particular stream reach. Some of these, such as the black fly larva, require fast water. Others, such as the immature forms of caddisflies and mayflies, will develop to large populations in more sluggish water. Among many invertebrate genera there are those particular species that are adapted for life not only under the two extremes of flow but also under its many variations.

Silt

The deposition of sediments in streams can and often does destroy insect and mussel populations. Ellis (1931), in studying the Mississippi, Tennessee, and Ohio Rivers, reported that erosion silts had destroyed a large portion of the mussel population in various streams by directly smothering the animals in localities where a thick deposit of mud was formed, and by smothering young mussels even where the adults could maintain themselves. Ziebell (1957) reported a marked reduction in organisms 100 yards downstream from the discharge of a gravel washing operation entering the South Fork Chehalis River in Washington. Ziebell and Knox (1957) investigated the effects of yet another gravel washing operation on the Wynooche River in Washington. The results of bottom samples collected downstream from the operation revealed reductions of 75 to 85 percent at distances exceeding 1 mile. Silt from a gravel washing plant located on Cold Creek and the Truckee River, Calif. reduced bottom organisms over 75 percent for a distance of more than 10 miles downstream (Cordone and Pennoyer, 1960). Reports published by the Oregon State Game Commission summarized the results of extensive collections of bottom organisms upstream and downstream from gold dredge operations on the Powder River (Anon., 1955). During siltation, production of fish food organisms decreased to nearly zero in the zone of heaviest pollution and the effect of siltation extended for a distance of 20 miles. In about 1 year after the dredge closed operations, the silt was flushed from the pools and riffles by freshets and bottom organisms increased 8 to 10 fold in weight per unit of bottom area.

Few data are available regarding the direct harm of sediments to fish. In most cases indirect damage to the fish population through destruction of the food supply, eggs, or changes in the habitat probably occur long before adult fish are harmed directly. Ellis (1944) stated that particulate matter of a hardness greater than one, if held in suspension by current action or otherwise, will injure the gills and other delicate exposed structures of fishes, mollusks, and insects when the particles are large enough. Kemp (1949) stated that mud or silt in suspension will clog or cut the gills of many fish and mollusks, and he considered 3,000 p.p.m. dangerous when maintained for a period of 10 days. Wallen (1951) conducted controlled aquarium investigations on the direct effects of turbidity on warm water fishes; he found that observable behavioral reactions that appeared as a turbidity effect did not develop until concentrations of turbidity neared 20,000 p.p.m. and in one species reactions did not appear until turbidities reached 100,000 parts per million (p.p.m.).

The effects of silt upon fish eggs and the developing fry has received greater attention. Stuart (1953) concluded that silt is not very dangerous in the normal streams if excess occurs only at intervals; however, the character of such normal streams can be drastically altered by allowing the washings of quarries, gravel pits, and mines to flow into the streams untreated. In many cases the quantities allowed to enter the stream may be small and the materials in suspension may in itself be of a nontoxic character, but continous application of small quantities over the reeds may by much more detrimental to the welfare of very young fish than sudden flushes of large quantities. Others who have noted the detrimental effects of silt upon the eggs and developing fry of fish include Campbell (1954), Snyder (1959), and Shapovalov and Berrian (1940). Shapovalov and Taft (1954) in discussing mining silt concluded that from a practical standpoint the damage to spawning beds would occur when mining silt enters a stream at times other than storm periods when the water velocity is insufficient to carry the sediment in suspension.

Turbidity reduces the enjoyment of fishing and may limit fishing success. This effect has been determined in expressable data for Fork Lake in Illinois where it was found that the fish caught per man-hour decreased from 6.53 to 2.04 when the transparency in feet as measured by the Secchi disc was likewise reduced from an average of 4.0 to 1.3 (Bennett, Thompson, and Parr, 1940).

Buck (1956) in a study of 39 farm ponds, rotenoned and then stocked with largemouth bass and bluegill or largemouth bass and redear sunfish were classified into clear ponds-turbidities less than 25 p.p.m., intermediate ponds-turbidities from 25 to 100 p.p.m., and muddy ponds-turbidities in excess of 100 p.p.m. At the end of two seasons, the average total weight of all fish in clear ponds was about 1.7 times greater than in intermediate ponds and 5.5 times greater than in muddy ponds. Largemouth bass were harmed the most by turbidity in both growth and reproduction. Average volume of net plankton in surface waters of clear ponds was 8 times greater than in intermediate ponds and 12.8 times greater than in muddy ponds.

Sediment is believed to destroy algae by molar action, by simply covering the bottom of the stream with a blanket of silt, or by shutting off the light needed for photosynthesis. Tarzwell and Gaufin (1953) found that turbid waters may transport the byproducts of bacterial action on organic wastes and the effluent of sewage treatment plants considerable distances before they are utilized. When water clears as a result of impoundment so that phytoplankton can grow, fertilizing materials are utilized and may produce troublesome blooms far from the source of pollution. Corfitzen (1939) found that the greatest loss in light intensity was due to light absorption by silt with some additional loss by reflection and refraction.

Attached algae and vegetation are affected by silt principally by: (1) Covering bottom materials with a layer of sediment, (2) reducing light transparency and preventing light penetration, and (3) grinding algae by action of abrasive particles. A reduction of plant food is accompanied by a reduction in the poundage of plant feeding animals that can be supported, and this in turn limits the production of carnivorous animals including fish.

The European Inland Fisheries Advisory Commission, Food and Agricultural Organization of the United Nations, prepared water quality criteria on finely divided solids (Anon., 1965). With respect to chemically inert solids and to waters that are otherwise satisfactory for the maintenance of freshwater fishes they made the following conclusions:

> "(a) There is no evidence that concentrations of suspended solids less than 25 p.p.m. have any harmful effects on fisheries.
>
> (b) It should usually be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 p.p.m. suspended solids. Other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in category (a).
>
> (c) Waters normally containing from 80 to 400 p.p.m. suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range.
>
> (d) At the best, only poor fisheries are likely to be found in waters which normally contain more than 400 p.p.m. suspended solids."

"In addition although several thousand p.p.m. solids may not kill fish during several hours or days exposure, such temporary high concentrations should be prevented in rivers where good fisheries are to be maintained. The spawning grounds of salmon and trout require special consideration and should be kept as free as possible from finely divided solids."

Oil

McKee (1956) in summarizing the effects of oil substances on aquatic life in freshwater, stated that:

"(1) free oil and emulsions may coat and destroy algae and other plankton;
(2) heavy coatings of free oil on the surface may interfere with the natural processes of reaeration and photosynthesis, while light coatings would be less detrimental because wave action and other turbulence would maintain adequate reaeration; and
(3) water soluble principles may exert a direct toxic action."

The deleterious effect of crude oil and lubricating oils on fish is due to a film formed over the gill filaments of fish, which prevents the exchange of gasses and results in suffocation (Klinke, 1962).

The effects of oils on marine animals may include the tainting of fish and shellfish flesh, poisoning by ingestion of oil or soluble fractions, such as phenol, ammonia, and sulfides, disturbances of marine food chains, physical fouling of animals with heavy coats of oil, and repellent effects (Hawkes, 1961).

Many thousands of waterfowl have been destroyed by the effects of oil pollution. This wasteful loss has deprived nature lovers, waterfowl hunters, and bird watchers of immeasurable enjoyment. The destruction of many duck species, such as the canvasback, redhead, and scaups, comes at a critical period for these species that are fighting for survival against the forces of nature. In future years additional waterfowl will be destroyed if oil dumping is continued, especially in late winter. In this modern age of technical development, the discharge of oil into a river system indicates man's lack of responsibility for the preservation of our natural resources.

Erickson (1965) pointed out that the effects of oil on birds depend upon a variety of factors including the type of oil, extent of contamination of plumage, temperature of the air and water, and the quantity of oil ingested. He found that migratory birds are affected indirectly by deposits of oil on the bottom, in shallow water, or along the shore that reduces the available food supply of both plants and animals. Elements within the food chain are eliminated by chemical or physical properties of the oils and food for waterfowl may become unavailable by being overlayed or embedded in the oily materials. Accumulation of petroleum sludge may also prevent germination and growth of plants and the production of invertebrates important as food, either by smothering or by toxic effects.

Oil causes matting of the duck feathers so that ducks become waterlogged, lose their ability to fly and drown if they cannot get out of the water soon enough. It breaks down the insulating power of the feathers; body heat and stored reserves of energy are rapidly lost. Diving ducks may starve, and, following the preening of oil from contaminated feathers, bleeding ulcers may be produced in the digestive tract causing mortality.

Major Nutrients

Eutrophication is a term meaning enrichment of waters by nutrients through either man-created or natural means. Present knowledge indicates that the fertilizing elements most responsible for lake eutrophication are phosphorus and nitrogen. Iron and certain "trace" elements are also important. Sewage and sewage effluents contain a generous amount of those nutrients necessary for algal development.

Lake eutrophication results in an increase in algal and weed nuisances and an increase in midge larvae, whose adult stage has plagued man in Clear Lake, Calif., Lake Winnebago, Wis., and several lakes in Florida. Dense algal growths form surface water scums and algal-littered beaches. Water may become foul-smelling. Filter-clogging problems at municipal water installations can result from abundant suspended algae. When algal cells die, oxygen is used in decomposition, and fish kills have resulted. Rapid decomposition of dense algal scums, with associated organisms and debris, gives rise to odors and hydrogen sulfide gas that creates strong citizen disapproval; the gas often stains the white lead paint on residences adjacent to the shore.

Nitrogen and phosphorus are necessary components of an environment in which excessive aquatic growths arise. Algal growth is influenced by many varied factors: vitamins, trace metals, hormones, auxins, extracellular metabolites, autointoxicants, viruses and predation and grazing by aquatic animals. Several vitamins in small quantities are requisite to growth in certain species of algae. In a freshwater environment, algal requirements are met by vitamins supplied in soil runoff, lake and stream bed sediments, solutes in the water, and metabolites produced by actinomycetes, fungi, bacteria, and several algae.

Evidence indicates that: (1) High phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth promoting factors are present; (2) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (4) phosphorus concentrations critical to noxious plant growths vary, and they produce such growths in one geographical area, but not in another. Potential contributions of phosphorus to the aquatic environment have been indicated in the literature (table 2).

Keup (1968) in flowing water studies found that phosphorus is temporarily stored in bottom sediments or transported as a portion of the stream's bed-load after its removal from the flowing water. Long-term storage is affected when the phosphorus is pooled in deltas or deposited on flood plains. Keup reviewed the literature on phosphorus discharges by specific streams (table 3).

Once nutrients are combined within the ecosystem of the receiving waters, their removal is tedious and expensive; removal must be compared to inflowing quantities to evaluate accomplishment. In a lake, reservoir, or pond, phosphorus is removed naturally only by outflow, by insects that hatch and fly out of the drainage basin, by harvesting a crop, such as fish, and by combination with consolidated bottom sediments. Even should adequate harvesting methods be available, the expected standing crop of algae per acre exceeds 2 tons and contains only about 1.5 lbs of phosphorus. Similarly, submerged aquatic plants could approach at least 7 tons/acre (wet weight) and contain 3.2 lbs/acre of phosphorus. Probably only half of the standing crop of submerged aquatic plants can be considered harvestable. The harvestable fish population (500 lbs.) from 3 acres of water would contain only 1 lb. of phosphorus.

Dredging has often been suggested as a means of removing the storehouse of nutrients contained within the lake bed sediments. These sediments are usually rich in nitrogen and phosphorus, for they represent the accumulation of years of settled organic materials. Some of these nutrients are recirculated within the water mass and furnish food for a new crop of organic growth.

Hasler (1957) found that, in an undisturbed mud-water system, the percentage of nutrients, as well as the amount of phosphorus that is released to the superimposed water, is very small. In laboratory experiments, when P^{32} is placed at various depths in the mud, the diffusion into the overlying noncirculating water is negligible, if the phosphorus is

Table 2. Pounds of Phosphorus Contributed to Aquatic Ecosystems

Major Contributors:

Sewage and Sewage Effluents: 3 lbs. per capita per year.*
Some industries, e.g., potato processing: 1.7 lb. per ton processed.
Phosphate rock from 23 States (Mackenthun and Ingram, 1967).
Cultivated agricultural drainage: 0.35–0.39 lb. per acre drained per year (Engelbrecht and Morgan, 1961) (Sawyer ,1947) (Weibel, 1965).
Surface irrigation returns, Yakima River Basin: 0.9–3.9 lbs. per acre per year (Sylvester, 1961).
Benthic Sediment Releases.

Minor Contributors:

Domestic duck: 0.9 lb. per year (Sanderson, 1953).
Sawdust: 0.9 lb. per ton (Donahue, 1961).
Rainwater.**
Groundwater, Wis.: 1 lb. per 9 million gals. (Juday and Birge, 1931).
Wild duck: 0.45 lb. per year (Paloumpis and Starrett, 1960).
Tree leaves: 1.8–3.3 lb. per acre of trees per year (Chandler, 1943).
Dead Organisms; animal excretions.

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*Various researchers have recorded the annual per capita contribution of phosphorus in pounds from domestic sewage as 2 to 4 (Bush & Mulford, 1954), 2, 3 (Mentzler et al., 1958), 1.9 (Owen, 1953), and 3.5 (Sawyer, 1965).

**Influenced by pollution present in atmosphere "washed out" by rainfall.

Table 3. Phosphorus Discharged by Selected North American Streams (from Keup, 1968)

Principal land use	River	Number of analyses	Season of sampling	Drainage area (mile²)	P—P (lb/annum/ mile²)	Population density mile²	Reference *
Forested	West Branch Sturgeon R, Mich	27+	July	14	37	Sparse	A.
	Pigeon, Minn	4	Aug. and Sept	600	28	Sparse	B, C, D.
	Poplar, Minn	4	Aug. and Sept	114	21	Sparse	B, C, D.
	Baptism, Minn	4	Aug. and Sept	140	42	Sparse	B, C, D.
	St. Louis, Minn	4	Aug. and Sept	3430	58	Sparse	B, C, D.
	Bois Brule, Wis	4	Aug. and Sept	113	97	Sparse	B, C, D.
	Bad, Wis	4	Aug. and Sept	611	78	Sparse	B, C, D.
	Montreal, Wis	4	Aug. and Sept	281	98	Sparse	B, C, D.
	Black, Mich	4	Aug. and Sept	202	65	Sparse	B, C, D.
	Presque Isle, Mich	4	Aug. and Sept	260	39	Sparse	B, C, D.
	Ontonagon, Mich	4	Aug. and Sept	1290	44	Sparce	B, C, D.
	Yakima, Wash	?	Annual	182	473	Sparse	E.
	Tieton, Wash	?	7 months	237	492	Sparse	E.
	Cedar, Wash	?	Annual	125	204	Sparse	E.
	Mulligan, Maine	12	4 seasons	21	4	Sparse	F.
	Stetson, Maine	19	4 seasons	29	20	Sparse	F.
	East Branch Sebasticook, Maine	56	4 seasons	56	128†	> 63‡	F.
Agricultural	Ellerslie, Prince Edward Island	≈44	April–Dec	10	113	Sparse	G.
	Pigeon, N. C	18	July	133	97	Light	This article.
	Johnathans, N. C	5	July	65	201	Light	This article.
	Kankakee, Ind. and Ill	6	June–Sept	5280	139	28	H, I.
	Vermillion, Ill	8	June–Sept	1230	179	36	H, I.
	Fox, Ill. and Wis	7	June–Sept	2570	489	145	H, I.
	Kaskaskia, Ill	100	April–Dec	5220	225	>174‡	J.
	Streams near Madison, Wis	?	?	?	235–262	?	K.
Urban	Du Page, Ill	5	June–Sept	325	18	380	H, I.
	Des Plaines, Ill. and Wis						
	Above confluence with Chicago River	5	June–Sept	635	570	1270	H, I.
	Total basin (includes Chicago River)	19	June–Sept	2180	4020	2570	H, I.
	Chicago, Ill	16	June–Sept	810	6540	5650	H, I.

*Data given, or computed from data in the refernces. A. Ball and Hooper (1963), B. Putnam and Olson (1959), C. Putnam and Olson (1960), D. Anon. (1964), E. Sylvester (1961), F. Anon. (1966), G. Smith (1959), H. Hurwitz, et al. (1965), I. Anon. (1963), J. Engelbrecht and Morgan (1961). K. Sawyer (1947).

†One seasonal (9 months) industry contributes approximately 75 per cent. ‡Only sewered population known.

placed more than 1 c.m. in the mud. Application of lime to the water or mud reduces the amount of soluble phosphorus released. Acidification of previously alkalized mud will, upon agitation, increase the amount of phosphorus entering solution. In an aquarium experiment, circulation of the water above phosphorus-rich mud, with the aid of air bubbles, increased the phosphorus in solution.

Zicker et al. (1956) found in laboratory experiments that the percentage of phosphorus released to water from radioactive superphosphate fertilizer placed in an undisturbed mud-water system was very small, with virtually no release of phosphorus from fertilizer placed at depths greater than ¼ inch below the mud surface. Radiophosphorus placed ½ inch below the mud surface showed only a very slight tendency to diffuse into the water, while the radiophosphorus placed at a 1-inch depth did not diffuse into the water at all.

Dredging deepens an area within a lake and can be beneficial if the increased depth is sufficient to prevent growth of larger nuisance plants. Dredging uncovers yet another soil strata that will contain phosphorus in some quantity, subject to solution in water. The newly dredged area immediately begins to receive organic fallout from waters above, and forms a new interface at which nutrient exchange is substantial. Sediments disturbed during a dredging operation liberate nutrients at a rate more rapid than sediments left undisturbed and all of these factors must be considered when recommending dredging for nutrient removal. Based entirely on nutrient considerations, dredging can be advantageous only when it removes sediments that contain a higher concentration of nutrients than the interface likely to be formed by fallout.

The total supply of an available nutrient depends on the total volume of water, as well as the concentration of the element in the water. Gerloff and Skoog (1957) in laboratory investigations determined that 5 units of nitrogen plus 0.08 unit of phosphorus (a ratio of 60:1) would produce 100 units of algae. The N–P ratio, as it naturally occurs in algae and submerged plants, is more nearly 10:1. Allen (1955) found that to obtain any appreciable increase it was necessary to supplement the sewage with nitrogen as well as carbon.

Sawyer (1947) studied the southeastern Wisconsin lakes and concluded that a 0.30 mg/l concentration of inorganic nitrogen (N) and a 0.01 mg/l concentration of soluble phosphorus (P) at the start of the active growing season could produce nuisance algal blooms. Nitrogen appears to be the more critical factor limiting algal production in natural waters (Gerloff and Skoog, 1957), since phosphorus is stored in plankton as excess and may exceed the actual need.

Sawyer (1954) discussed factors that influence the development of nuisance algal growths in lakes. The surface area is important since the accumulations of algae along the shoreline of a large lake under a given set of wind conditions could easily be much larger than on a small lake,

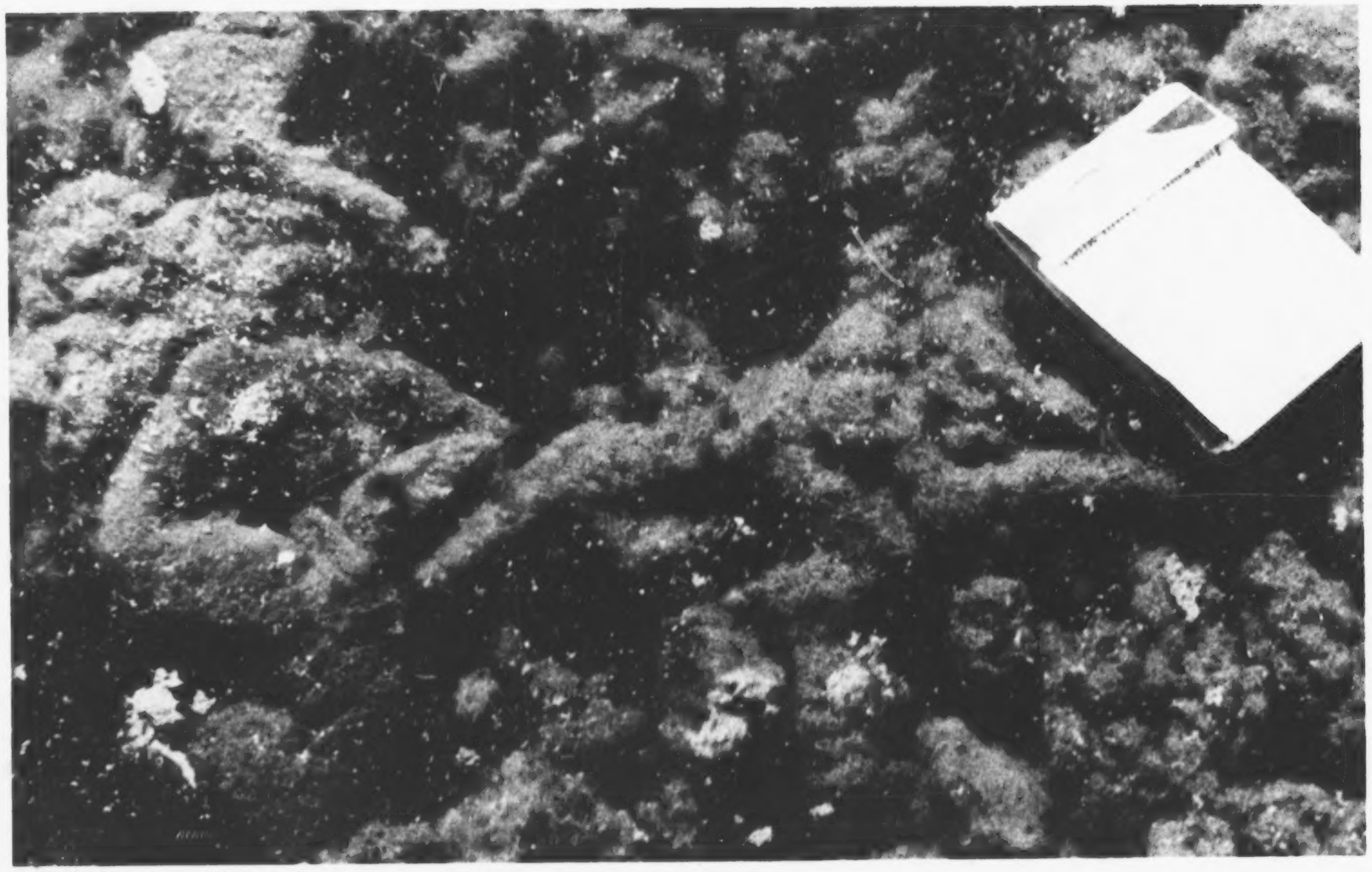

Figure 9. A Blue-green Algal Nuisance

under equal fertilization per acre. The shape of the lake determines to some degree the amount of fertilizing matter the lake can assimilate without algal nuisances since prevailing winds blowing along a long axis will concentrate the algal production from a large water mass into a relatively small area. The most offensive conditions develop during periods of very mild breezes that tend to skim the floating algae and push them toward shore. Shallow lakes, too, respond differently from deep stratified lakes in which the deeper waters are sealed off by a thermocline. In the nonstratified waters all the nutrients dissolved in the water are potentially available to support an algal bloom. In stratified waters, only the nutrients confined to the epilimnion are available except during those brief periods when complete circulation occurs.

Lund (1965) in his thorough literature review stated that "Nitrogen and phosphorus can still be considered as two of the major elements limiting primary production. In some tropical and highly eutrophic temperate lakes, nitrogen may be a more important limiting factor than phosphorus. In many other lakes phosphorus is present in very low concentrations and seems to be the major factor limiting production. Evidence from the addition of fertilizers to fish ponds and from what is known about the eutrophication of lakes by sewage supports the view that phosphorus plays a major role in production."

Chu (1943) found that optimum growth of all organisms studied in cultures can be obtained in nitrate-nitrogen concentrations from 0.9 to 3.5 mg/l and phosphorus concentrations from 0.09 to 1.8 mg/l, while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l downward and in phosphorus concentrations from 0.009 mg/l downward. The lower limit of optimum range of phosphorus concentration varies from about 0.018 to about 0.09 mg/l; and the upper limit from 8.9 to 17.8 mg/l when nitrate is the cource of nitrogen, while it lies at about 17.8 for all the planktons studied when ammonium is the source of nitrogen. Low phosphorus concentrations may, therefore, like low nitrogen concentrations, exert a selective limiting influence on a phytoplankton population. The nitrogen concentration determines to a large extent the amount of chlorophyll formed. Nitrogen concentrations beyond the optimum range inhibit the formation of chlorophyll in green algae.

Experiments by Ketchum (1939) with the diatom *Phaeodactylum,* showed a reduction in rate of cell division when phosphate present in the medium is less than 17 micrograms per liter (μg/1) P. Strickland (1965) stated that the limiting phosphorus concentration in some cultures has been found to be less than 5 μg/l. The problem is complicated because auxiliary compounds may affect the availability of phosphate to a plant cell. Sylvester (1961) found that nuisance algal blooms were observed in Seattle's Green Lake (a very soft-water lake) when nitrate nitrogen (N) levels were generally above 200 μg/l and soluble phosphorus (P) was greater than 10 μg/l.

Müller (1953) concluded that excessive growths of plants and algae in polluted waters can be avoided if the concentration of nitrate nitrogen is kept below about 0.3 mg/l and the concentration of total nitrogen is not allowed to rise much above 0.6 mg/l.

The question is sometimes asked, how much algae can be grown from a given amount of phosphorus? Allen (1955) found that the maximum that could be grown in the laboratory on sewage was 1 to 2 g/l (dry weight) and in the field in sewage oxidation ponds the maximum was 0.5 g/l. Thus, assuming optimum growth conditions and maximum phosphate utilization, the maximum algal crop that could be grown from 1 pound of phosphorus would be 1,000 pounds of wet algae under laboratory conditions or 250 pounds of wet algae under field conditions. Considering a phosphorus (P) content of 0.7 percent, 1 pound of phosphorus could be distributed among 1,450 pounds of algae on a wet weight basis.

A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 μg/l P at any point within the flowing stream, nor should 50 μg/l be exceeded where waters enter a lake, reservoir, or other standing water body. Those waters now containing less phosphorus should not be degraded (Mackenthun, 1968). Adequate phosphorus controls must now be directed toward treatment of nutrient point sources and to wastewater diversion around the lake or dilution within the lake, where feasible.

Micronutrients

It is generally conceded that abundant major nutrients in the form of available nitrogen and phosphorus are an important and a necessary component of an environment in which excessive aquatic growths arise. Algae, however, are influenced by many and varied factors. Vitamins, trace metals, hormones and auxins, extracellular metabolites, autointoxicants, viruses, and predation and grazing by aquatic animals are factors that stimulate or reduce algal growths. Some of these may be of equal importance to the major nutrients in influencing nuisance algal bloom production.

Harder, in 1917, is credited with first connecting growth inhibiting substances with algae. As early as 1931, autoinhibiting substances were recognized (Akehurst, 1931). These papers gave rise to a common belief that a plant can create its self-destruction through the production of growth inhibiting substances that it cannot tolerate but which may, in turn, stimulate other growths. Natural waters contain these active agents that are secreted and excreted by freshwater algae. The toxicity of these agents to other algae and bacteria and to fish varies constantly and is not well understood in the natural aquatic environment. It has been postulated that algae secrete not just one substance but several, some antibiotic, others stimulating. The amount secreted and the net result of the secretions would be determined by the prevelence of one group of substances over the other. Thus, sequences of algal blooms may be expected to occur under conditions of a nutrient supply far in excess of critical values.

In man's quest to reduce major nutrients enriching waters, such as nitrogen and phosphorus, and thereby restore such waters to a greater water use potential without attendant algal pests, other algal population-influencing factors will have a role in the ultimate success of the restoration efforts. This role is presently neither clearly defined nor understood. It does seem clear that the constant progression of the geologic clock cannot be substantially altered. Despite man's most ardent dreams, lakes now fertile and abundantly productive of algae will never again attain their crystal-clear, pristine appearance so well imprinted in the minds of long-time local residents. The old-swimmin-hole lingers on in local folklore. Recently defiled waters can be improved substantially, however, by reducing or removing the varying causes of algal productivity. By placing all known algal population influencing factors in their proper perspective and by intensifying investigative efforts directed towards the interrelationships of factors most likely to effect population controls, knowledge and nuisance reducing efforts will be enhanced. Lakes, reservoirs, ponds, flowing streams, estuaries, and bays will be improved, and the using public will be benefited.

Eyster (1964) divided the elements required by green plants into macronutrients and micronutrients. Macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, magnesium, calcium (except for algae where it is a micronutrient), and sodium. Micronutrients include iron, manganese, copper, zinc, molybdenum, vanadium, boron, chlorine, cobalt, and silicon.

Manganese is one of the key elements in photosynthesis and manganese-deficient cells have a reduced level of photosynthesis and a reduction in chlorophyll. Iron is associated with nitrogen metabolism. Arnon (1958) confirmed that chloride is a coenzyme of photosynthesis specifically concerned with oxygen evolution. Vanadium and zinc appear to be involved in photosynthesis. Calcium and boron are involved in nitrogen fixation. Molybdenum is necessary for nitrate utilization and nitrogen fixation. Cobalt is associated with the nutritional functions of vitamin B_{12}.

Fitzgerald (1964) discussed the sequences of algal blooms that occur under conditions of nutrient supply in sewage stabilization ponds far in excess of those found in natural lakes. He also reviews some of the factors other than nutrition that might influence the algal population. These factors include grazing and the production of inhibiting extracellular products. It is pointed out that there is evidence that an inverse relationship frequently exists between the density of phytoplankton and zooplankton. This might be the result of over-grazing in specific areas and a lack of grazing in adjoining areas or it may be due to an "exclusion" effect on zooplankton produces by extracellular plant metabolites. Gibor (1957) has shown evidence that algae can at times pass through the zooplankton without being affected by digestive processes.

In situations where the algae are so abundant that their control may be required by chemical means, it appears that animal predation or attacks by micro-organisms are not enough to cause a shift in the dominant species. Once the dominant species is eliminated, however, other species increase in numbers and become dominant. Factors thought to contribute to species dominance include secreted or excreted inhibiting extracellular products (Rice, 1954).

Léfevre (1964) stated that when an algal species develops extensively in standing waters causing waterblooms, it eventually becomes intoxicated by its own accumulated excretion products and dies. When the water is renewed slowly, this phenomenon does not occur because the extracellular products are constantly removed. Also, when one species of algae predominates in standing water, other species appear only sporadically and the number of bacterial species decreases. Léfevre et al. (1952) suggested that this phenomenon is due to antagonistic substances produced by the prodominant species. Léfevre (1964) stated that the production of extracellular active agents is conditioned by: (1) Nature of strain; (2) composition of culture medium; (3) nature and size of inoculum; (4) temperature; (5) illumination; (6) agitation of medium; (7)duration of culture; and (8) season of the year.

Of 154 algal species, 56 require no vitamins and 98 species require vitamin B_{12}, thiamin and biotin, alone or in various combination (Provasoli, 1961). Those blue-green algae not requiring B_{12} employ it readily as a cobalt source; since cobalt is generally scarse in water, even organisms not requiring B_{12} may compete for it. A great part of the vitamins in freshwaters and in the littoral zone of the sea can be assumed to come from any soil run-off especially during the spring floods. Muds are another source of vitamins. A third source is the vitamins present as solutes in water.

Vitamins are synthesized by several organisms. *Chorella* has been found to produce as much as 6.3 μg B_{12} per 100 g. of dry algae and *Anabaena* as much as 63 to 110 per 100 g. of dry algae (Brown et al., 1955). Burkholder (1959) studied the production of B vitamins by 344 bacteria isolated from waters and muds from Long Island Sound and found that 27 percent of these gave off vitamins B_{12}, 50 percent gave off biotin, 60 percent thiamine, and 11 percent nicotinic acid. Sixty-five percent of the actinomycetes studied were found by Burton and Lockhead (1951) to produce vitamin B_{12}. Robbins et al. (1950) reported that fungi and many bacteria, isolated from the water and mud of a pond in which *Euglena* blooms, produces B_{12}; they demonstrated also that these bacteria, grown with *Euglena* on agar plates of a medium deprived of B_{12}, diffused sufficient vitamin to support growths of *Euglena*. And Robbins and Kavanagh (1942) stated that the ability of a fungus to synthesize vitamins essential for their metabolic processes may be complete, incomplete, or absent.

Toxic Substances

Many pesticides and heavy metals are toxic to aquatic life in low concentrations. Many studies have related these toxicities to specific organisms and to specific dilution waters. The toxicity of a particular substance is dependent to a large extent on other water quality characteristics associated with the toxicant, such as temperature, pH, alkalinity, etc. The National Technical Advisory Committee (Anon., 1968) presented criteria for many of these elements and compounds based upon the present state of the art. In many instances it is necessary to determine through bioassay the toxicity to fish or other aquatic organisms by testing the particular effluent discharged with the particular water quality that receives the discharge.

4

PROBLEM SOLVING

SOLVING a field water quality problem involves the following principal points:

A. Objectives

B. Investigation

  1. Study Planning
  2. Data Collection
  3. Sample and Data Analyses

C. Reporting

  1. Data Organization and Display
  2. Interpretation
  3. Report Writing
     a. Introduction
     b. Summary
     c. Conclusions
     d. Recommendations
     e. Predictions
     f. Area Description
     g. Water Uses
     h. Waste Sources
     i. Effects on Water Quality
     j. Appendix

D. Demonstrations

Objectives

Careful thought should be given to the development of study objectives. These should encompass clear, concise, positive definitions of the investigation's purpose, its scope, and its boundary limitations. Study objectives should be realistically oriented to the numbers. competencies and disciplines of investigative personnel involved, to budgetary limitations for the study, and to the length of time allocated to the study, including final report preparation. Ultimately as the study progresses and it concluded, its success and accomplishments will be judged on the satisfaction, or degree of satisfaction, of the objectives stated at the instigation of the project. Study objectives become extremely important tools to guide and control subsequent investigation, to delineate avenues of approach towards problem solving, and eventually to judge success.

Planning

A field investigation encompasses three equally important areas of activity: study planning, data collection, and sample and data analyses. Study planning involves a myriad of details.

First, maps of the waterway in question must be secured and points of access noted. Tentative sampling stations should be selected from the maps based on points of access, and stream-mile designations developed for major landmarks on the waterway and the tentatively selected sam-

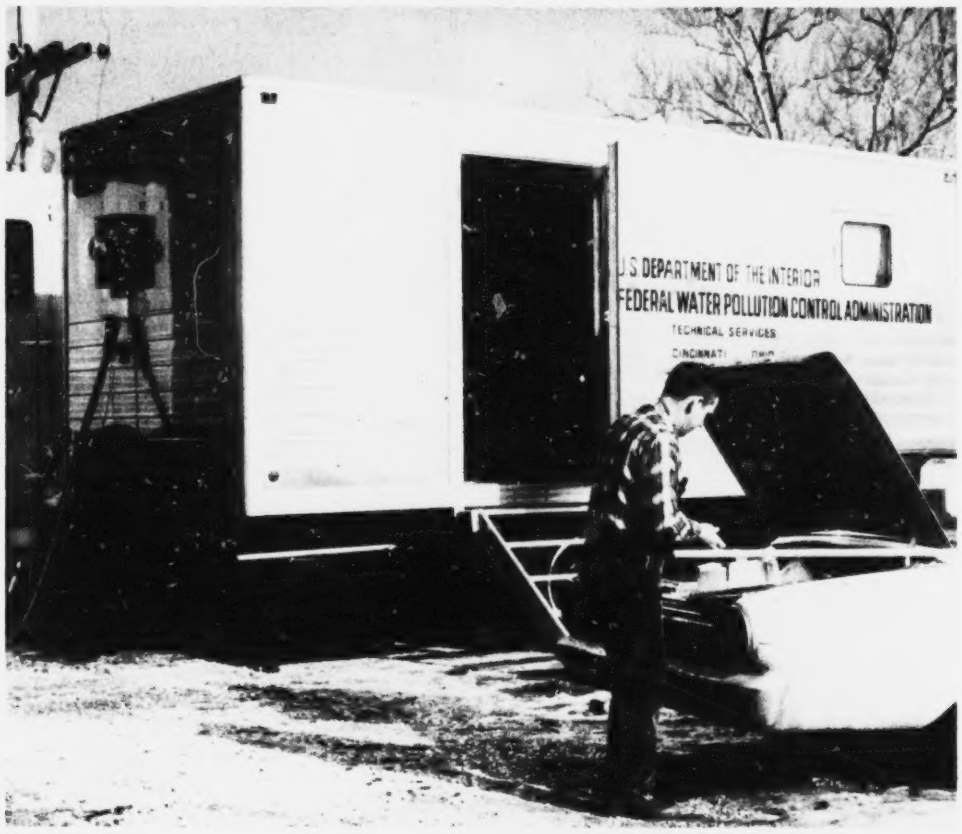
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
TECHNICAL SERVICES
CINCINNATI OHIO

Figure 10. Mobile chemical and microbiological laboratories receiving samples near river bank.

2

pling stations. Development of stream mileages necessitates that the maps be accurate and of suitable scale.

Following a "desk top" analyses of available background data and other information related to the problem in question, a reconnaissance survey is indicated of the reach of waterway to be studied, as well as principal contributing pollution sources. During the reconnaissance survey a judgment is reached on the potential effects on water quality of individual waste sources, the reach or reaches of waterway that are of potentially greatest concern in the particular investigation, and possible sampling sites and actual points of access. A judgment should be reached on the advantages and disadvantages of sampling the entire waterway by boat as opposed to a cartop or trailered boat that is lowered into the water from several points of access along the waterway. Perhaps answers to the problem can be satisfactorily obtained by sampling the stream while wading and, should this be the case, much time, effort, and expence could be saved in so doing. Observations should be made at various points of access on stream width, depth if ascertainable, nature and type of stream bed, relative flow, as well as any other morphometric features that would seem to contribute towards a better organized sampling procedure when samples are collected. It is extremely important to know where boats and other equipment may be lowered into the waterway and possible difficulties that may be encountered when this is done. It is equally important to ascertain that proportion of the samples that may be collected by wading or by some means other than by boat. Observations should be made that may later relate to the use of such gear as conventional biological sampling dredges, square foot stream samplers, and various types of fish nets or seines. During the reconnaissance survey contacts can be made with local officials or local investigators who may be encouraged to participate in some manner with the investigation. Arrangements should be made with land owners to cross private lands at times when samples are to be collected from the waterway, should this be necessary.

Water samples for chemical analyses should be collected from access points along the waterway during the reconnaissance survey to ascertain the relative magnitude of pollution at various points, and to aid in the judgment of selecting sampling stations. Concurrently the aquatic organisms that can be observed qualitatively on rocks and other submerged objects should be noted and recorded for similar use.

Following the completion of a reconnaissance survey, and subject to modification or change during the course of the field sampling, decisions can be made on the following:

1. Types of samples necessary to point to a solution to the problem (i.e. plankton, periphyton, benthos, vascular plants or fish)
2. Sampling points for each of the selected types of samples

3. Periodicity of sampling and approximate collection time for a specific sample type and
4. Approximate number of samples necessary to complete the study.

A field investigation of a problem that demands the services of a biologist or the collection of biological samples should be investigated also by the chemist, the microbiologist, the sanitary engineer, and perhaps a representative of another pertinent discipline. It goes without saying that particular points in the development of solutions to specific problems are not confined specifically to the biological discipline, but instead must be a consideration of any discipline's representative engaged in the study. Thus, the points that are discussed herein are related specifically to the biologist but can be used with appropriate modifications for associated disciplines. Indeed, biological data will serve to complement chemical, physical, and other data in the process of formulating a solution to a specific problem.

The next aspect of study planning involves, logically, the carrying out of details that are necessary to initiate the process of data collection. Decisions must be made on methods of sample handling, sample preservation, and transportation of samples to a base laboratory. In the conduct of biological investigations these decisions are often not complex. Samples are placed in appropraite sample containers, usually preserved with a solution of formaldehyde and transported to a base laboratory either at the completion of the field study or at intervals by commercial transportation. The number of samples expected to be collected during an investigation will determine the relative number of sample collection containers that must be made ready for the study. Sampling equipment, data cards, notebooks and all of the necessary paraphernalia associated with the collection, retention, and shipment of biological samples must be organized and arrangements made to transport same to the study site either at the study instigation or by commercial means in time to ensure its being on hand when the investigators arrive.

A part of the study planning involves the making of travel arrangements, room accommodations, transportation of samples and equipment both to and from the sampling area, and arragements for such items as outboard motor gasoline, cartons for shipping collected samples, and ice for sample preservative, if this is a necessary consideration.

Adequate survey planning can save so much time and expense during the field study that it is worthwhile to make a list of judgments that are necessary during this planning stage, as well as a list of items that are necessary to ensure a succesful survey. By checking this list one can reduce the possibility of oversight that otherwise would be a cause of frustration at a later time.

In addition, a preliminary survey of pertinent literature is of extreme importance. Data that are already available may serve as guides to addi-

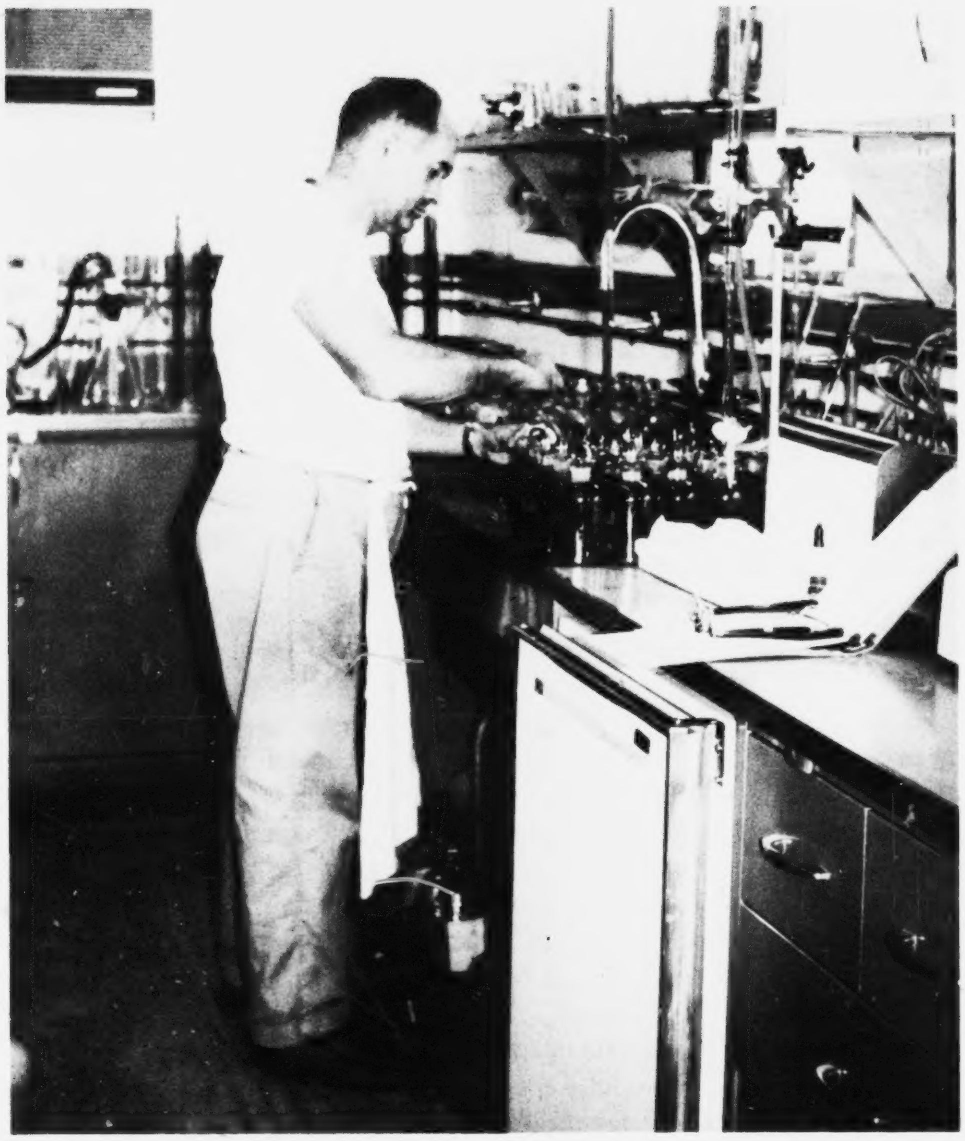

Figure 11. Laboratory analyses being conducted inside mobile laboratory.

tional investigation. A thorough study of the most complete maps of the study area will facilitate both organizational planning and initial field investigation.

Station Selection

Preliminary to the collection of a sample, the investigator must firmly establish the location of sampling stations. Station selection varies with the physical features of the waterway and this discussion will relate to streams, lakes, reservoirs, and estuaries.

Biological sampling stations for the stream environment should be routinely located close to or at those sampling stations selected for chemical and microbiological analyses to enhance interpretation through the use of interrelated data. Sampling stations should be located upstream and downstream from suspected pollution sources, and from major tributary streams, and at appropriate intervals throughout the stream reach under investigation. The upstream stations should depict conditions unaffected by a pollution source or tributary. The nearest downstream station to the pollution source or tributary should be so located that it leaves no doubt that conditions depicted by the sample can be related to the cause of any environmental change. The minimum number of downstream stations from this point should be located in the most severe area of the zone of active decomposition, downstream in an area depicting less severe conditions within this zone, near the upstream reach of the zone of recovery, near the downstream reach of the recovery zone, and in the downstream reach that first shows no effect from the suspected pollution source. Precise station location will depend on the flow, the strength, volume and type of pollution entering at the source, and the entrance of additional sources of pollution to complicate the stream recovery picture. When water in tributary streams is found to be polluted or to influence water quality in the primary stream, these streams should be similarly investigated.

A stream usually is composed of riffles and pools. These areas will vary in depth, velocity of flow, and types of substrate that form the stream bed. Because the biologist seeks to determine changes that occur in water quality as depicted by aquatic organisms and to relate these changes to particular sources, he must compare observations at a particular station with observations and findings from an upstream station, as well as a station within the stream reach that is unaffected by a suspected source. To accomplish this an effort should be made to collect samples from habitat types that are morphometrically similar. Riffle samples should be compared with riffle samples and pool samples compared with pool samples. Both should be studied where feasible. To determine the extent of each major environmental change produced by pollution, the biological investigator may need to choose a number of stations in addition to those selected for routine chemical or bacteriological sampling.

Plankton samples are collected usually at one point within the study station, most commonly at midstream 1 to 2 feet below the surface. Samples for bottom associated organisms should be collected at a number of points on a transsection line between the stream banks. Optimally, these samples should be collected at a minimum of (5) points across the stream (mid and two quarter points and at near zero water level with banks); more than one sample may, at times, be collected from each point and retained separately. Realistically the objectives of a particular survey and the number of stations at which bottom fauna are collected may dictate the number of samples from a particular station. Attached growths are sampled wherever they occur.

The receiving waters from a lake or reservoir should be studied in the same manner as influent streams. The effluent of a natural lake will usually give a better than average composite of the epilimnionic waters of the lake. The discharge from a reservoir penstock located below the thermocline, however, will not give a representative sample of the productive zone of the reservoir but shows water quality in a portion of the hypolimnion instead. A study would be indicated to show the effect of the low-level discharge on the receiving waters.

Within the lake or reservoir, a number of sampling sites may be chosen depending on the problem under investigation and the conditions to be studied. An investigation of the kinds and relative abundance of aquatic vegetation would naturally be limited to the littoral area. A mapping of aquatic plants often proves useful for future comparisons. Fish sampling

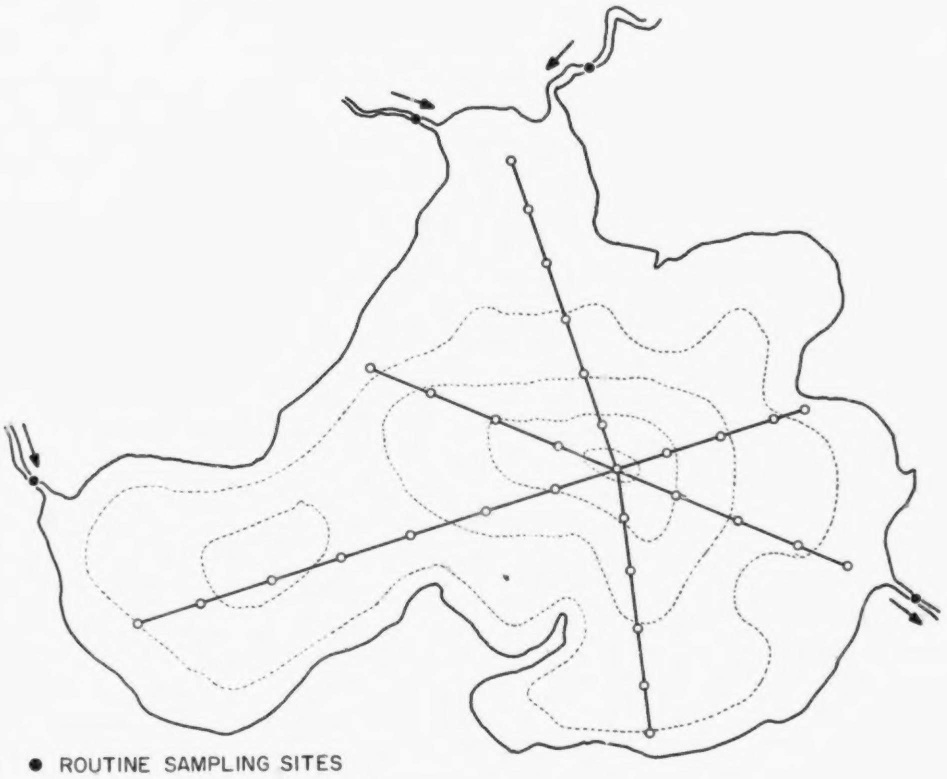

Figure 12. Diagram of a natural lake basin showing suggested sampling sites. Samples taken from points on transaction lines on a periodic or seasonal basis are valuable to determine vertical water characteristics and the benthic standing crop.

also is often more profitable in shallow water areas, although gill nets set in the region of the thermocline and below may sample a fish population not usually observed in shallow water.

The use of transections in sampling a lake bottom is of particular value because there are changes in depth and because benthos concentration zones usually occur. Unless sampling is done systematically and at relatively close intervals along transections, especially those that extend across the zone between the weed beds and the upper extent of the hypolimnion, concentration zones may be missed entirely or inadequately represented. Maximum benthic productivity may occur in the profundal region. Because depth is an important factor in the distribution of bottom organisms, productivity is often compared on the basis of samples collected from similar depth zones. Collections from a transection will sample all depth zones, and a sufficient number of samples must be taken to make the data meaningful.

A circular lake basin should be sampled from several transections extending from shore to the deepest point of the basin. A long narrow basin is suitable for regularly spaced parallel transects that cross the basin perpendicular to the shore, beginning near the inlet and ending near the outlet. A large bay should be bisected by a transection originating near shore and extending to the lake proper.

There are definite advantages in sampling the benthic population in winter beneath the ice cover in lakes. Samples can be collected at definite, spaced intervals on a transection, and the exact location of sampling points can be determined. Also, collections are at a time of peak benthic population when emerging insects do not alter the benthic population.

Transactions also aid in sampling the palnkton population. Because of the number of analyses necessary to appraise the plankton population, however, more strategic points are usually sampled, such as water intakes, a site near the dam in the forebay area or discharge, constrictions within the water body, and major bays that may influence the main basin. Because of significant population variation, plankton samples must be taken vertically at periodic depths, and at different times over the 24-hour day.

Reservoirs are usually long and narrow water bodies with the widest portions occuring downstream. They are particularly suitable for the placement of imaginary transection lines that extend perpendicularly from one shore to the opposite shore. Sampling stations can be conveniently located on these transections. In addition water use return waters or areas designated for water use removals should be sampled.

The selection of sampling stations in estuaries combines the aspects of stream sampling with those of the more static lake environment. Water within the estuary is controlled by tides and the force of water discharged by the river and, because of this, particular constituents of water quality

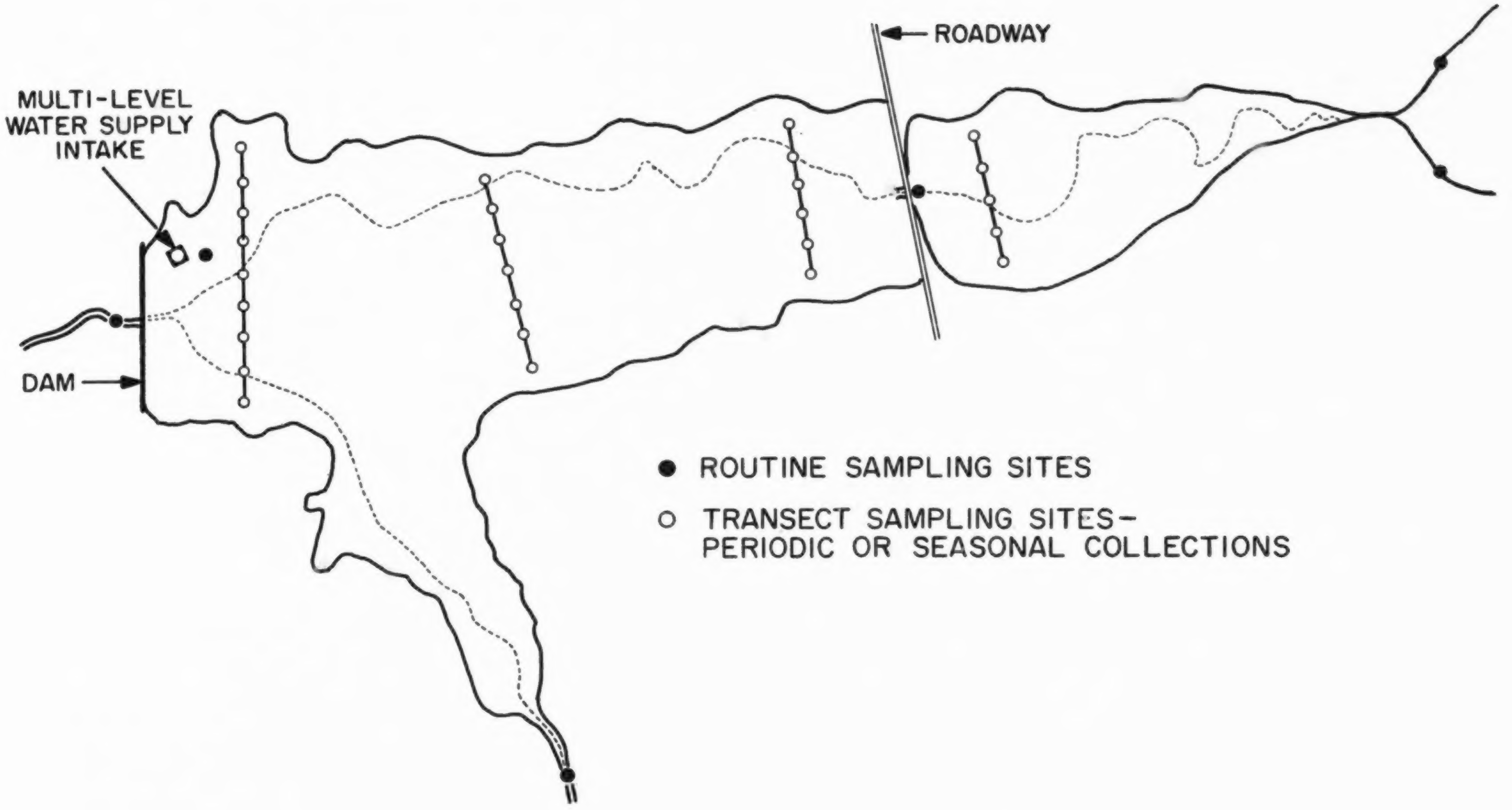
ROADWAY
MULTI-LEVEL WATER SUPPLY INTAKE
DAM
● ROUTINE SAMPLING SITES
○ TRANSECT SAMPLING SITES–PERIODIC OR SEASONAL COLLECTIONS

Figure 13. Diagram of a long, narrow reservoir showing suggested sampling stations.

may remain localized in a given area for a considerable period of time before they are dispersed or carried out to sea. Thus, the flow characteristics of the water mass are extremely important in order to define water quality and prognosticate effects of waste discharges on it. The flowing water portion of an estuarine study should be attacked in a manner similar to that described for the stream environment. Sampling stations within the true estuary can be profitably developed along transection lines that either cross the estuary, more or less perpendicularly from one shore to another, or that extend out of the estuary in two or more directions from a suspected point source of pollution. Whenever possible, samples should be collected from areas that represent the estuarine habitat unaffected by pollution, as well as areas that depict environmental changes produced by it.

Sampling Periodicity

Weekly collections, as a minimum, are desirable throughout the season of active biological growth to measure planktonic populations and chemical constituents that may change rapidly. In special studies, samples are often collected daily or even periodically during a 24-hour day to assess these changes. During the non-growing season, monthly samples of these constituents should be adequate except where otherwise indicated by the objecives of the study. A reconnaissance and mapping of the aquatic vegetation should be done during maximum vegetation growth, usually in midsummer.

Insect representatives of the bottom organism community emerge from the water as adults periodically throughout the warm weather period; time of emergence depends on the species involved. Life histories of these organisms tend to overlap so that at no time is there a dearth of these organisms within the bottom associated community. Bottom fauna should be sampled during the annual seasons; the standing crop will be highest, however, during the fall and winter periods when insect emergence is minimal, and one of the sampling dates should reflect this period.

Because of the report deadline or limited personnel available, the theory and practice of station location and sampling periodicity may not be the same. The objectives of a study may be met by investigating only bottom fauna and attached organisms in a stream, and these on only one occasion. Much can be learned from this minimal effort. The investigator should keep in mind that water quality effects from organic wastes will likely be at their worst during the warm weather low-flow period. When streams become covered with ice in northern climes during winter, another period with severe conditions of existence for bottom fauna occurs in late winter. The zone of active decomposition resulting from an organic waste source will be transferred a considerable distance downstream under ice cover.

Little knowledge may be gained from only one series of plankton samples from a stream. Because these organisms are carried by the currents, a given sample is representative of water quality at some point upstream rather than at the place of sampling.

Data and Sample Collection

The collection of data and samples from a particular station involves making a number of scientific observations. Flow measurements on streams, inlets and outlets to standing bodies of water such as lakes and reservoirs, suspected municipal and industrial waste sources, and water use drawoff and return points, which can be correlated with sampling dates, are of utmost importance. Such data permit a calculation of the amounts of particular water quality constituents passing a point at a given time, and estimates can be made from these data on daily, monthly, or annual contributions. Rainfall may be a contributing factor to investigations concerning major aquatic plant nutrients and should be sampled to determine annual contributing amounts of nitrogen and phosphorus. A house-to-house survey of the area draining to a watercourse may be indicated to determine types of waste treatment and to project potential impact of wastes that are discharged to or reach the watercourse. The types and amounts of fertilizers applied to lands within the drainage basin, as well as the period of the year when fertilizers are applied, may be of importance to the study. Groundwater may be a factor and should be sampled from appropriate adjacent wells for those constituents of importance.

On approaching a stream station a number of observations must be made that will later be considered in interpreting the biological findings.

Observations are made on water depth; presence of riffles and pools; stream width; flow characteristics; bank cover; presence of slime growths, attached algae, scum algae, and other aquatic plants, as well as red sludgeworm masses; and unusual physical characteristics such as silt deposits, organic sludge deposits, iron precipitates, or various waste materials from manufacturing processes.

Organisms associated with the stream bed are studied most often in the biological evaluation of water quality. These organisms are valuable to relate water quality because they are not equipped to move great distances through their own efforts and, thus, remain at fixed points to indicate water quality. Because the life history of many of these organisms extends through 1 year or longer, their presence or absence is indicative of water quality within the past, as well as the present. Bottom associated organisms are relatively easy to capture with conventional sampling equipment and the amount of time and effort devoted to their capture and interpretation is not as great as that required for other segments of the aquatic community.

The investigator should ask himself three basic questions: Based on a knowledge of preferred organism habitats, what bottom fauna should I expect to find at this station? Specifically, where would I expect to find these creatures? What is the appropriate gear with which to capture them? A close search of the respective areas should be made noting and collecting qualitatively the various types of organisms. A commercial 30-mesh sieve is a handy exploratory tool.

The qualitative search for benthos should involve the collection of organisms from rocks, plants, submerged twigs or debris, or leaves of overhanging trees that become submerged and waterlogged. It is often convenient to scrape and wash organisms from these materials into a bucket or tub partially filled with water and then to pass this water through the sieve to concentrate and retain the organisms. The collected sample may be preserved for organism sorting and identification later. The investigator should search until he is certain that he has collected the majority of species that can tolerate the particular environment. In some environments it

FIELD COLLECTION CARD

Date ________ Hour ______ Collector ____________

Field Designation ______________________

Station Location ______________________

Sample No. ______________ Stream Miles ________

Weather ______________________________

Bottom: ____ Rock: ____ C. Gravel F. ____: C. Sand F. ____

% : ____ Sandy Loam: ____ Silt Loam: ____ Silt:

: ____ C. Clay F. ____ : ____ Organic Sludge:

Sample Location ______________ Sample Depth ________

River: Width ________ Depth ________ Current ________

: Temp ________ DO ________ pH ________

: Phth Alk ________ Tot Alk ________ Cond ________

Sampler	Ek	Pet	Sq Ft	Qual		
No. of Samples:						

Fish: Gear	Shocker	Dip Net	Seine		
Sample Time					
Sample Area					

Remarks:

Figure 14. Field Collection Card for Benthic Samples.

Desired items for a field biological collection card may be arranged on a 5″ × 8″ unlined card for convenience. Cards can be carried in a field notebook; they may be filed after field and laboratory use. The backside of the card may be ruled to itemize the organisms observed in the laboratory examination of the collected sample.

is possible only to collect qualitative samples because the physical nature of the waterway may be such that quantitative sampling is not feasible.

Qualitative sampling determines the variety of species occupying a reach of a waterway. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but they generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced in the stream because of adverse conditions from 100 to 1 per square foot, whereas sludgeworms may increase from 1 to 14,000 per square foot. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms.

The basic principal in qualitative sampling is to collect as many different kinds of animals as practical. Obviously, because of the rarity of some forms, the probability of collecting a specimen of every kind is remote and a limit must be imposed on the collector's efforts. Two convenient limiting methods are:

(1) Presetting a time limit on the collector's effort at each sampling point. A minimum of 30 minutes and a maximum of an hour is a convenient range in which to establish this limit.

(2) Sampling in an area until new forms are encountered so infrequently that "the law of diminishing returns" dictates abandoning the sampling point. This method requires professional judgment —but if after 10 minutes only a single species or organism is found, the sampler can move to the next sampling site where he might continue to find new forms after searching more than an hour.

A number of tools readily obtained in any community are valuable in this type of sampling:

a. Pocket-knives are excellent tools to remove animals from crevices in rocks, to peel bark from decaying logs thus exposing animals, and to slip under animals to lift and transfer them to sample containers.

b. Mason jars in ½ to 1 pint sizes serve as the most economical sample containers and provide visibility of the preserved specimens.

c. Common garden rakes are valuable to retrieve rocks, brush, logs and aquatic vegetation for inspection.

d. Fine-meshed dip-nets are good devices for sweeping animals from vegetation or out from under over-hanging rock ledges.

e. Buckets are handy to quickly receive rocks and debris, thus preventing escape of the swift running animals.

f. Sheet polyethylene, 6 x 6 feet, can be spread on the stream bank and substrate materials placed upon it. As the materials begin to dry the animals will abandon their hiding places and can be seen readily as they migrate across the sheet seeking water.

g. U.S. Standard Series No. 30 soil sieves can be used to scoop up fine sediments and sieve out its inhabitants. The entire qualitative sample can also be screened to standardize the organism sizes taken at various sampling sites.

h. Any other tools, such as forceps, scalpels, shovels, and forks are legitimate devices and can prove their merit in individual situations.

Following these general observations, the investigator collects appropriate quantitative samples of the various kinds of organisms present in the aquatic area. He makes certain that: (1) The sampling area selected is representative of stream conditions, and (2) the sample is representative of and contains those forms predominant in the area and encountered during the qualitative search.

Bottom samples in lakes usually may be collected with an Ekman dredge, although the physical composition of the bottom determines to a great extent the type of samples that must be used to collect an adequate sample. The Ekman dredge (Ekman, 1911) consists of a square box of sheet brass 6 x 6 inches in cross section.* The lower opening of this box is closed by a pair of strong jaws so made and installed that they oppose each other. When open, the jaws are pulled apart so that the whole bottom of the box is open; the jaws are held open by chains attached to trip pins. To close the dredge, the trip pins are released by a brass messenger sent down the attachment rope and the jaws snap shut by two strong external springs. The hinged top of the box may be equipped with a permanent 30-mesh screen to prevent loss of organisms if the samples sinks into mud deeper than its own height. The sampler is especially adapted for use in soft, finely divided mud and muck; it does not function properly on sand bottoms or hard substrates. The Ekman can also be mounted on a pipe for shallow stream sampling and tripped by a thrust-through rod.

The Petersen dredge (Petersen, 1911) is a most versatile stream bed sampler to collect bottom life. It is widely used to sample hard bottoms such as sand, gravel, marl, clay, and similar materials. It is an iron, clam-type dredge, samples an area of 0.6 to 0.8 square foot, and weighs between 35 and 70 pounds depending on the rare use of additional weights that may be bolted to its sides. By means of a rope, the dredge is slowly lowered to the bottom to avoid disturbing and flushing away significant lighter materials. As tension is eased on the rope, the mechanism holding the jaws apart is released. As the rope is again made taut, a sample is secured. The operator controls the dredge by maintaining tension on the rope until the dredge is placed. This is helpful in sampling gravel or rubble, as the operator can determine through sound and touch the type of bottom and by carefully manipulating the dredge, can secure a better sample than would otherwise be possible. In streams with gravel and rub-

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* Ekmans are made also in 9″ x 9″ and 12″ x 12″ sizes, but because of size of grabs, these are almost impossible to operate effectively on many occasions. Through long experience the author recommends only the 6″ x 6″ size.

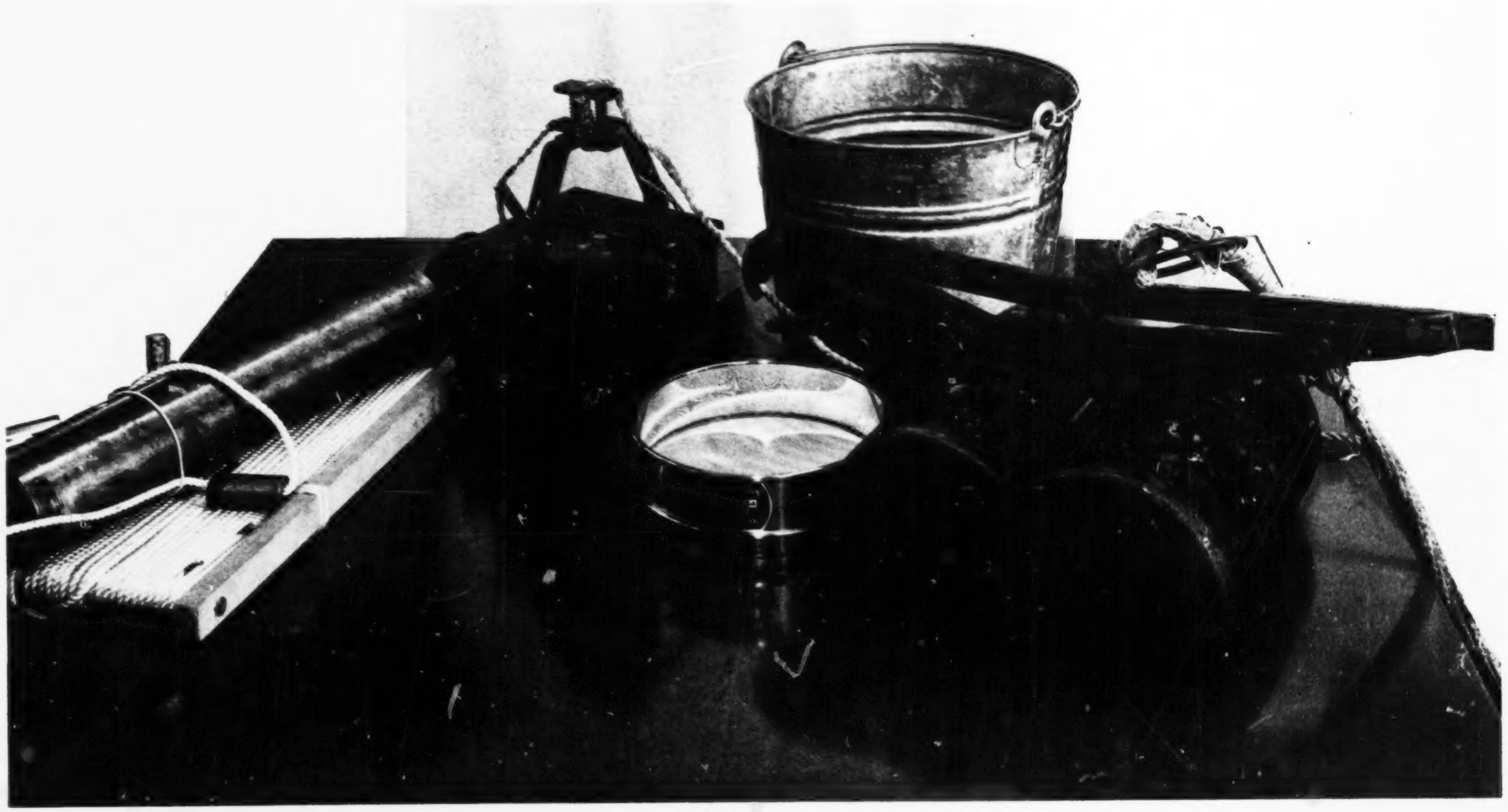

Figure 15. Biological collecting equipment. From left, Kemmerer sampler, Ekman dredge, U.S. Standard No. 30 sieve, washing bucket, and Petersen dredge.

ble beds that permit wading, another technique is for the investigator to place the dredge and then stand on the jaws working them into the stream bed with his weight, thus gradually closing them. When the dredge is surfaced, careful and rapid placement and subsequent discharge, endwise, of the dredge into a bucket whose lip is placed at the water's surface prevents loss of material.

The orange-peel dredge, is a multijawed, round dredge with a canvas closure serving as a portion of the sample compartment. It is available in a variety of sizes. Its sampling area is a function of depth of penetration and this area must be calibrated, usually with the volume of sediment contents. It has received wide use in marine waters and in the Great Lakes, where it has advantages over other tools for sampling sandy substrates.

The ponar dredge is receiving increased use in deep lakes. In comparative studies it is more efficient than the Petersen dredge when samples are secured from deep (>100 feet) waters. In appearance it is similar to a Petersen dredge but it has side-plates and a screen on the top of the sample compartment.

The Smith-McIntyre dredge has the heavy steel construction of the Petersen, but its jaws are closed by strong coil springs. Its principal advantage is its stability or operator control in rough waters. Its bulk and heavy weight requires operation from large boats equipped with a powered winch.

Core samplers have been used to sample sediments in depth and collect small areas (2–4 sq. inches) of the mud-water interface. Their efficient use requires dense animal populations. Corer design varies from hand-pushed tubes to explosive driven and automatic surfacing models. The Phleger type is the most widely used corer in water quality studies. It is a gravity corer, relying on its weight (near 100 lbs.) to drive its sample tube into the substrate. The length of core retained will vary with substrate texture; 30 inches is near the maximum length. A core of this length is adequate for most physical, chemical or fossil examination to delineate recent environmental changes.

The Wilding, or stove-pipe, sampler is the only sampler that will quantitatively sample the fauna inhabiting the bottom and/or the vegetation in areas with dense aquatic weed growths. Its operation may be restricted to the vegetation, or mud-water interface sediment may be included.

Drift nets may be suspended in flowing waters to capture invertebrates that have migrated into the water mass from the bottom substrates and are temporarily being transported by currents. Their principal uses have been to study migratory movements and to evaluate sublethal toxicants, especially insecticides, on the fauna. Before toxicants become lethal the animals are weakened and cannot maintain their benthic position and thus are swept away by the currents and carried into the nets.

These nets must be standardized in an individual study. As of now no single style of net has been standardized among investigators. It is recommended that these nets be designed with a 1 x 1 foot upstream opening, with U.S. Standard Series No. 30 netting (or finer, with subsequent screening for uniform organism size), and with a net-bag length of 36 inches.

After suspension in the water, these nets require constant tending. Within a fraction of an hour the nets efficiency is reduced through clogging of the net by drifting animals and detritus that soon results in significant volumes of water and organisms being diverted around the mouth of the net.

Other sampling gear, and their uses, will be described in the 13th Edition of Standard Methods for the Examination of Water and Wastewater.

After the bottom sample is collected by one of the deepwater sampling devices, it is brought to the surface and placed in a large pail or tub. Water for sample dilution is added to the pail, and the sample is mixed into a slurry with the slurry finally being passed through a U.S. Standard No. 30 mesh sieve while the sieve is being rotated in the water. The washing operation is repeated until all fine material has passed through the sieve, and all organisms are retained in the sieve. The organisms and coarser debris are then removed form the sieve and are preserved. It is often easier to sort the organisms from the debris when the organisms are alive. Time schedules and extensive field operations, however, often dictate that sample collection and examination take place at different times during the year. Wide-mouthed, tapered pint freeze jars, obtainable from most grocery stores, have proven to be excellent bottom organism sample containers. When these jars are filled half full with 10-percent formalin before the days activities of sample collection, it is a time-saving process to transfer the concentrated sample from the side of the sieve to the jar of preservative by lightly hitting the sieve against the top of the jar. The investigator is assured always of a minimum of 5-percent formalin in the sample container, a sufficient strength to preserve the collected organisms. After the samples are preserved in the field they are returned to the laboratory where the organisms are separated from the debris, placed in respective groups, identified, and enumerated.

To sample riffle areas in streams, a square-foot bottom sampler, originally described by Surber (1936), is widely used. It consists of two 1-foot-square brass frames hinged together at right angles; one frame supports the net which is held extended downstream by current velocities, the other encloses the sampling area. In field operation, the sampler is so placed that organisms dislodged by hand from the substratum within the sampling frame will be carried into the net by the current. In stagnant or in slowly moving water, it often is not practical to employ this square-foot sampler.

In practice, it may be found convenient to remove the larger rocks from inside the sampling frame, placing them in a bucket or tub partially filled with water. Here, the organisms can be washed or scraped from the rocks, and concentrated by a sieve as described earlier, before being combined with those from the Surber sampler in a sample jar with preservative.

Artificial substrates have been successfully employed in studying bottom fauna in flowing streams. One multiple-plate sampler constructed of tempered hardboard (Hester and Dendy, 1962) has been especially suitable for studying stream inhabitants in those streams that do not possess a natural substrate suitable for the attachment of benthic forms. A sampler constructed of eight 3-inch squares, separated by seven 1-inch squares, and held in place by a bolt or threaded rod exposes slightly more than 1 square foot of surface to which organisms can attach.

Artificial substrates are placed in the water for 3- to 6-weeks and then carefully removed to prevent losing the organisms that have made them a temporary home. As nearly as possible the substrates should be placed at similar depths and in similar physical relationship to the stream at all stations. Usually they are placed about 1-foot beneath the surface or 1-foot off the stream bed. The multiple-plate sampler can be reduced in size to three plates only and placed vertically near the surface, at mid-depth, and near the bottom at a particular station. Loss of some substrates because of vandalism or flooding should be anticipated.

Periphyton include that assemblage of organisms that grow on free surfaces of submerged objects in water and cover them with a slimy coat. Cooke (1956) comprehensively reviews the literature on the subject. Periphyton play an important role in flowing waters because these organisms are the major primary producers in that environment. Thus, they are an important part of a lake or reservoir study of both the influent and receiving streams. A number of substrates have been proposed with which to study attached organisms including glass slides, cement blocks, wooden shingles, and plexiglass plates (Grzenda and Brehmer, 1960). Growths on such substrates may be analyzed qualitatively or quantitatively.

The type of artificial substrate employed to collect organisms is not terribly important as long as the same type is used at all such sampling stations in a particular investigation. Any type will be somewhat selective in those organisms that are attracted to it. They do tend to favor drift organisms or those that become detached from their dwelling areas and float downstream with the current. When the same type of sampler is used at each station, data collected among the stations should be comparable.

Patrick et al. (1954) developed a slide-carrying device, termed the Catherwood Diatometer, to sample the diatom populations of streams. It consists of a plastic base mounted on a lead bar shaped like a boat. On the plastic base are mounted two floats designed so that the depth to which the diatometer is sunk can be varied. Between the floats, behind a

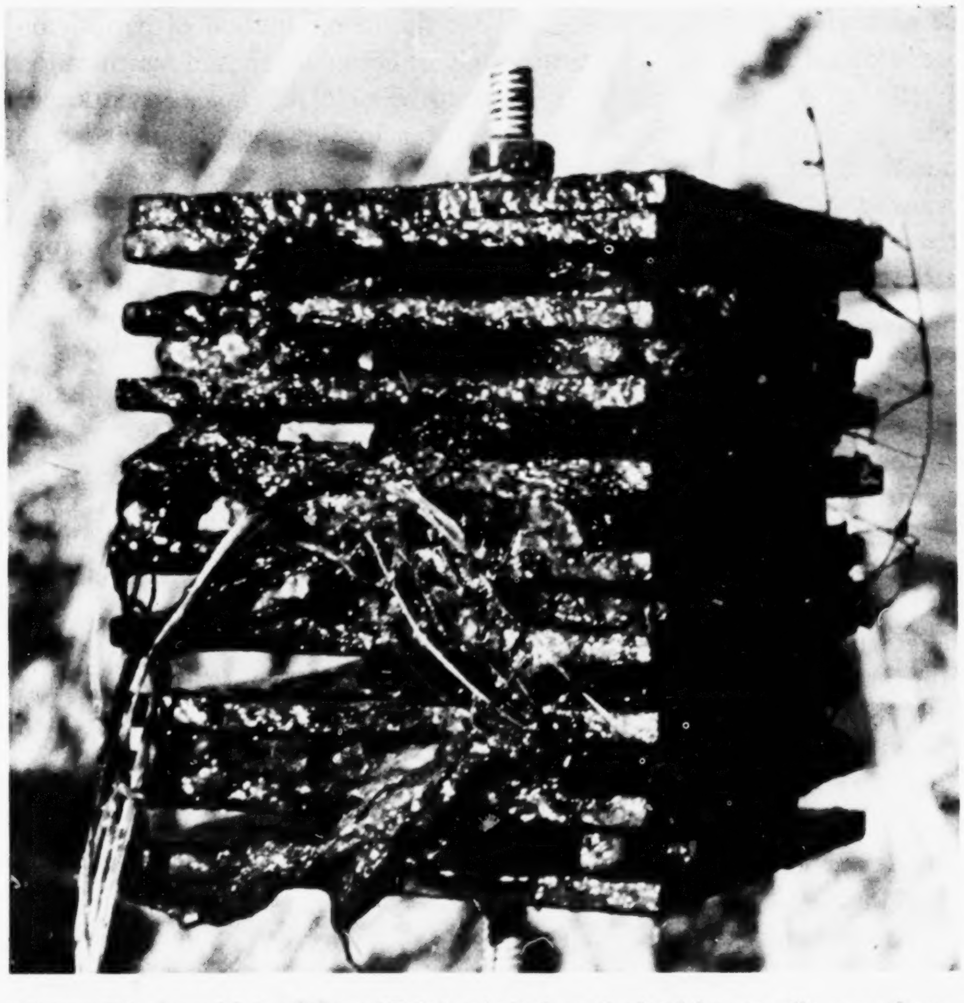

Figure 16. A multiple-plate artificial substrate colonized by aquatic organisms (Hester-Dendy type).

plastic V-shaped vane, the plastic slide holder slotted to hold six slides vertically is mounted edgewise to the current. The vane prevents excess washing of the slides. It was stated that 1 week was sufficient to expose the slides and that the population of an unpolluted stream could be estimated as adequately with this method as with the usual methods of collecting diatoms. Calculations upon which these estimates are based must be corrected when dealing with polluted streams.

A comprehensive review on limnological methods to investigate periphytic communities has been prepared by Sladeckova (1962). She lists 448 references as a bibliography and portrays a large number of devices on which attached organisms can grow and be sampled. In a summary she states that there is no single, universal method for the quantitative evaluation of periphyton for every purpose. An analysis of ecological factors influencing the periphytic community may make methods for the evaluation of this community on natural substrata preferable. On the contrary, the use of artificial substrata is essential for the determination of periphyton formation on a unit area or for the study of colonization and stratification of attached organisms, especially in deep water. The choice of exposure technique is often determined by circumstance. The duration of exposure must be tested in advance. Lund and Talling (1957) completed an earlier review with 777 references; they also discussed methods with special reference to algae, both planktonic and attached. Sladecek and Sladeckova (1964) discussed the glass slide method for the determination of periphytic production in particular. Methods were cited for the calculation of production rates.

In the study of attached organisms in waters receiving acid mine drainage, it was found that extreme corrosion of the slide holding device contributed to a substantial loss of samplers during the study period. A type of putty (Plasti-tak*) has been found to be extremely useful to secure microscope slides to clay bricks or to the upper fiber board plate of a multiplate sampler (Thomas, 1968). Advantages to this procedure include good holding power, noncorrosive aspects in acid or salt water, ease of artificial substrate placement, low cost, and removal of single slides without disturbing adjacent ones. The surface to which the adhesive is applied must be dry and clean and the adhesive will release in fast water after about 3 weeks.

To obtain a history of sediment deposition or to permit selection of strata within the sediments, sampling of these by a commercial core sampling device is expedient. Much information can be obtained of a historical nature and can be related to the problem under investigation through the chemical and biological examination of sediment cores.

Samples collected for plankton analysis are most often similar to those collected for the analyses of chemical water quality. They may be collected with the aid of a Kemmerer sampler or similar device that permits capture of a sample from a particular water strata.

Fish samples may be collected by nets, seines, poisons, and electrofishing. Electrofishing is conducted by means of an alternating or direct electrical current applied to water that has a resistance different from the fish. This difference in resistance to pulsating direct current stimulates the swimming muscles for short periods of time, causing the fish to orient and be attracted to the positive electrode. An electrical field of sufficient potential to demobilize the fish is present near the positive electrode, but decreases in intensity with distance. After the fish are identified, weighed, and measured, they commonly can be returned to the water uninjured.

The electrofishing unit may consist of a 110-volt, 60-cycle, heavy duty generator, an electrical control section, which is a modified commercially sold variable voltage pulsator, and electrodes. The electrical control section provides selection of voltages from 50 to 700 volts a.c. and 25 to

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*Mention of a commercial product does not constitute endorsement by the Federal Water Pollution Control Administration, U.S. Department of the Interior.

350 volts d.c. The a.c. current acts as a standby for the d.c. current and is used in cases of extremely low water resistance. The variable voltage allows control of field size in various types of water.

Meaningful samples of littoral vegetation may be difficult to secure. Sampling, per se, is often not necessary. It is usually sufficient to map, identify, and estimate abundance of the principal components of the aquatic vegetation population.

Comprehensive investigation of particular field problems may necessitate special investigative tools that can be developed through modification of existing tools. The development and use of these devices depends in large measure on the ingenuity and imagination of the investigator. Special studies that may be performed in conjuction with a field investigation would include the conduct of bioassays to test organisms in particular effluents or other substances where toxicity to aquatic life may be suspected. The procedure to conduct bioassays is well described in Standard Methods for the Examination of Water and Wastewater (Anon., 1965).

Sample Analyses

For a detailed discussion of the laboratory examination of biological samples, Standard Methods for the Examination of Water and Wastewater should be examined.

When samples are collected of animals associated with the lake or stream bed the organisms and debris are usually preserved with 10 percent formalin. The formalized sample is washed in the laboratory to remove the strong formalin solution. From this point it is necessary to remove and segregate the animals on which an interpretation will be made from the debris within the sample jar. A number of flotation methods have been proposed by various authors to reduce the time expended in this operation. When an investigation includes stream reaches that are heavily polluted with organic sludges or that produce prolific growths of slimes and other attached organisms, flotation methods do not work well. Thus, as a routine measure the somewhat laborious effort of separating organisms from debris through hand sorting must be employed.

A white enamel pan with a depth of approximately 1½" is often used in the hand picking operation. It is convenient to half fill the pan with water and then place 2 or 3 tablespoons of material from the sample jar in the center of the pan. By teasing the sample to all sides with the aid of forceps, small animals can be removed without difficulty. It is helpful for later indentification to keep the removed organisms separated into the taxonomic groups that are discernible with the unaided eye. When it is noted that organisms within the collected sample are limited to a few (2 to 4) kinds and are extremely abundant as they often are when sludgeworms reproduce in great numbers in organic sludge, samples may be split to reduce time and labor in removing organisms. This is accomplished by placing the sample in the white pan without water, leveling the sample surface, and randomly selecting ½, ¼, 1/16, or 1/32, of the sample for organism removal. When this is done, the entire sample should be examined for those larger organisms that may not be numerous. In reports written principally for those outside of the biological discipline, bottom faunal abundance is expressed usually as the number of a particular kind of organism per square foot. Organisms from a 6″ x 6″ Ekman dredge sample, for example, would be multipled by 4 to arrive at the number per square foot. When the sample is split and only an aliquot examined, the appropriate conversion multiplication must also be used. Further identification through the use of a stereoscopic microscope and counts to ascertain numbers within a particular group are made to facilitate interpretation of water quality.

Slimes and other attached growths are identified and estimates made of relative abundance. Quantitative methods are often employed. Chlorophyll determinations may be used as an indicator of those plants that possess this material and the determination is often helpful to separate attached algal quantities from slimes.

Chlorophyll, an enzyme present in green plants, in the presence of light converts carbon dioxide and water to basic sugar, a process that is termed photosynthesis. Chlorophyll increases in lakes as the lakes become more eutrophic; thus chlorophyll measurements provide comparative data on

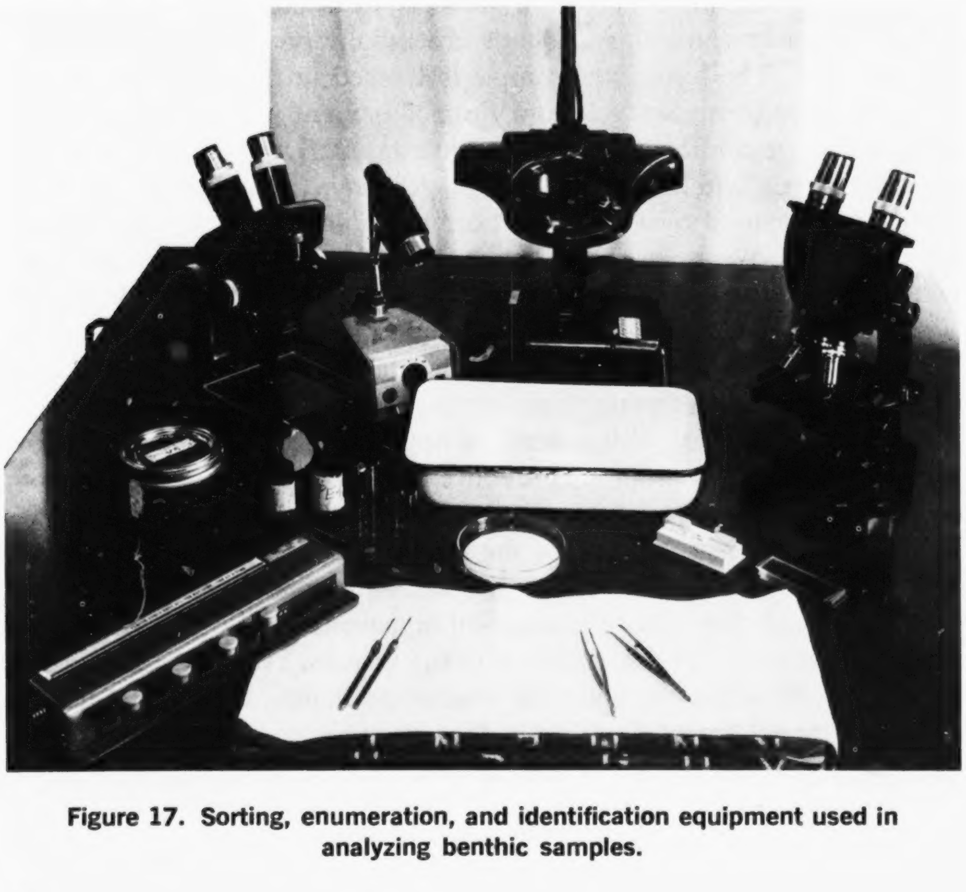

Figure 17. Sorting, enumeration, and identification equipment used in analyzing benthic samples.

eutrophication (Deevey and Bishop, 1942; Kozminski, 1938; Manning and Juday, 1941; Anderson, 1961).

The quantity of chlorophyll has also been used as a general index of the quantity of algae present (Harvey, 1934; Riley et al., 1949; Tucker, 1949). Chlorophyll is related closely to primary production or the conversion of organic materials to living plant tissue (Manning and Juday, 1941; Ryther and Yentsch, 1957; Odum et al., 1958). Because a large quantity of algae may be present, but not growing, and conversely a small population of algae may exhibit a substantial growth rate, the quantity of algae may not be related directly to primary production. Factors such as light intensity, nutrient availability, temperature, age or viability of algal cells, and size of the cells influence the quantity of chlorophyll per unit of algae present (Odum et al., 1958).

Chlorophyll-bearing cells may be filtered from the water with membrane filters (0.45 micron pore). Filters and cells are placed in vials of acetone for extraction of the pigments and for solution of the filters (Creitz and Richards, 1955). Samples are then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone is examined on a recording spectrophotometer. Spectrums are evaluated and the quantity of chlorophyll determined as outlined by Richards with Thompson (1952).

Some waters contain sufficient plankton (phyto- and/or zooplankton) so that samples must be diluted to obtain adequate numerical information; however, with a sparse plankton sample, concentration should be used. The phytoplankton in samples from most natural waters require neither dilution nor concentration and should be enumerated directly. Correspondingly, zooplankton often are not sufficiently abundant to be counted without concentration. Selection of methods and materials used in plankton enumeration depends on objectives of the study, density of plankters in the waters being investigated, equipment available, and experience of the investigator.

The Sedgwick-Rafter cell has been and continues to be the most commonly employed device for plankton enumeration because it is easily manipulated and provides reasonably reproducible information when used with a calibrated microscope equipped with an eyepiece measuring device, usually a Whipple ocular micrometer. It can be used to enumerate undiluted, concentrated, or diluted plankton samples. The biggest disadvantage associated with the cell is magnification. The cell cannot be used for enumerating very small plankton unless the microscope is equipped with special lenses that provide sufficient magnification (400X or greater) and clearance between objective lenses and the cell.

The Sedgwick-Rafter cell is 50-mm. long by 20-mm. wide by 1-mm. deep. Since the total area is 1,000 mm.^{2}, the total volume is 1×10^{12} cubic μ, 1,000 mm.^{3}, or 1 ml. A "strip" the length of the cell thus constitutes a volume 50-mm. long, 1-mm. deep, and the width of the Whipple field.

Two or four strips usually are counted, depending on the density of plankters. Counting more than four strips is not expedient when there are many samples to be enumerated; concentrating procedures then should be employed, and counts made of plankters in the concentrate.

$$\text{No. per ml.} = \text{Actual Count} \times \frac{1{,}000}{\text{Volume of ``strip'' (mm.}^3\text{)}}$$

If the sample has been concentrated, the concentration factor is divided into the actual count to derive the number of organisms per ml. For separate field counts (usually 10 or more fields):

$$\text{No. per ml.} = \text{avg. count per field} \times \frac{1{,}000}{\text{Volume of field} \times \text{No. of fields}}$$

When special lenses are not used and there is a need to enumerate small plankton, unusually abundant, other procedures may be employed in conjunction with and related to counts obtained from the Sedgwick-Rafter cell.

Lackey (1938) used a drop counting method in his examination of Scioto River, Ohio, phytoplankton. In this method, the sample is first centrifuged and ". . . after thorough agitation by alternately sucking it in and spurting it out of the pipette, the exact number of drops was counted and a sufficient number of drops of the decanted portion was added, so that one drop of catch bore a definite relationship to the amount centrifuged." One drop of sample is put on a glass slide and a cover glass added; 5 low-power fields and 10 high-power fields are examined, and number of each species is recorded at the magnifications used. Enumeration is repeated on 3 such mounts for a total of 15 lowpower fields and 30 high-power fields.

No per ml = avg. no. per field × no. of fields per drop or per cover slip × no. of drops per ml ÷ the concentration factor.

The concentration factor = ml of original sample ÷ ml of concentrate × (100 — percent of preservative in sample).

Lackey's method has the advantages of including all organisms in the catch, simplicity and ease of manipulation, and instant use of the high power magnification where identification with the low power is questionable. Certain disadvantages are inherent in the method: (1) because water normally is used as a mounting medium enumeration must be accomplished relatively rapidly to prevent dessication and subsequnt distortion of organisms; (2) results are not sufficiently accurate when only one slide-mount is examined, thus necessitating preparation and enumeration of at least three or more slide-mounts; and (3) the investigator should be sufficiently familiar with plankton to rapidly identify and count the specimens encountered.

Application of the membrane filter method of plankton counting requires a vacuum pump, special filtering papers, and experience in determining the proper amount of sample to be filtered. Plankton in samples from waters containing substantial quantities of suspended matter such as silt may be difficult to enumerate by this method since, in the process of filtering, the suspended matter tends to crush the plankton or otherwise obscure them from view. However, the method has certain features that make it particularly adaptable for use on waters with a low phytoplankton and silt contents. Primary among these features, the method permits the use of conventional microscope lenses to achieve high magnification for enumeration of small plankton (the membrane filter retains very small organisms), provides relatively rapid processing of samples if the investigator is familiar with the procedure and the plankton, does not require counting of individual plankters to derive enumeration data, and increases the probability of observing the less abundant forms (McNabb, 1960).

The sample is filtered through a 1-inch membrane filter. The wet filter is removed and placed on top of 2 drops of immersion oil on a microscopic slide, and 2 drops of immersion oil are placed on top of the filter. The filter is air-dried at room temperature until clear (approximately 48 hours). A cover slip is added prior to examination.

When examined, the magnification and sampling field or quadrat must be of such size that the most abundant species will appear in at least 70 but not more than 90 percent of the microscopic quadrats examined (80 percent is optimum). Otherwise the field size or the amount of sample concentrated must be altered. The occurrence of each species in 30 random microscopic fields is recorded.

> Number of organisms per milliliter = density (d) from table 4 × number of quadrats or fields on membrane filter ÷ number of milliliters filtered × formalin dilution factor [0.96 for 4 percent formalin].

Plankton samples form the Madison, Wis., sewage treatment plant effluent diversion study (Mackenthun et al., 1960) were concentrated by settling with a liquid detergent and were counted by the drop technique. To concentrate the phytoplankton, 500 ml. of stream water were placed in l-liter glass settling cylinders to which were added 20 ml. of commercial formalin to preserve the sample, and 10 ml. of a detergent to settle the sample. Sedimentation of the plankton was complete in 24 hours, after which the supernatant was carefully siphoned from the cylinder, and the concentrate was washed into 100 ml. centrifuge tubes. These were spun at 2,000 r.p.m. for 6 minutes. The supernatant in the tube was decanted and the concentrate was washed into screw-capped storage vials and brought to the nearest 5 ml. by the addition of 4% formalin and the use of a volume standard. In making the drop count, 5 low-power fields and 10 high-power fields were observed on this slide, and the magnification as well as number of each species of organisms was recorded. This procedure was repeated on 3 such mounts so that totals of 15 low-power fields

Table 4. Conversion Table for Membrane Filter Technique (Based on 30 Scored Fields)

Total occurrence	F%	d
1	3.3	0.03
2	6.7	0.07
3	10.0	0.10
4	13.3	0.14
5	16.7	0.18
6	20.0	0.22
7	23.3	0.26
8	26.7	0.31
9	30.0	0.35
10	33.3	0.40
11	36.7	0.45
12	40.0	0.51
13	43.3	0.57
14	46.7	0.63
15	50.0	0.69
16	53.3	0.76
17	56.7	0.83
18	60.0	0.91
19	63.3	1.00
20	66.7	1.10
21	70.0	1.20
22	73.3	1.32
23	76.7	1.47
24	80.0	1.61
25	83.3	1.79
26	86.7	2.02
27	90.0	2.30
28	93.3	2.71
29	96.7	3.42
30	100.0	?

$$\text{Where F} = \frac{\text{total number of species occurrences} \times 100}{\text{total number of quadrats examined}}$$

and 30 high-power fields were observed. The number of a particular type of organism in 1 liter of water was determined by the following formula:

$$\text{No./1} = \frac{(\text{Avg No./field})\ (\text{No. fields/coverslip})\ (\text{No. drops/ml}) \times 1{,}000}{\text{Concentration factor}}$$

$$\text{The concentration factor} = \frac{\text{ml. of original sample}}{(\text{ml. of concentrate})\ (0.94)}$$

where 0.94 accounts for the dilution of the sample by the addition of formalin and the detergent.

The average volume in cubic microns of each species was obtained by measuring 20 individuals. The volume contributed by each species was expressed in parts per million by use of the following formula:

$$\text{Volume (ppm)} = (\text{No. org/l})\ (\text{avg species vol in } \mu^3) \times 10^{-9}.$$

Palmer (Palmer and Maloney, 1954), developed a new counting slide for nannoplankton.

Mackenthun employed constable tubes to determine cell volume in a 1956 Wisconsin study. Concentrated algal samples were obtained on July 25, 1956, and again on August 8, 1956, from Station 1 in the Menasha Channel, Fox River, at mileage designation 38.5, at Station 2 from the Rapide Croche Dam at mileage designation 19.5, and Station 3 upstream from De Pere Dam at mileage designation 7.0. The concentrated algal samples were obtained by centrifuging 50 gallons of river water at 12,000 r.p.m. and suspending the residue in 1 gallon of algal-free water. A blender was employed in resuspending the algae. An aloquot sample of this 50 to 1 concentration was used for biological analyses.

Ten ml. of the concentrated samples, equivalent to 500 ml. of raw water, were centrifuged at an approximate speed of 2,000 r.p.m. in a constable tube. The addition of a small amount of detergent to the constable tube will facilitate the packing of small blue-green algae. On August 8, 50 liters of river water were strained through a fine plankton net at the 3 stations for comparative purposes. The cell pack or cell volume as calculated on a raw-water basis was as follows:

Cell pack (ml./1.)

		August 8	
Station	July 25	Centrifuged	Net plankton
1	0.068	0.086	0.071
2	.058	.066	.038
3	.036	.045	.031

Both the centrifuged and net plankton samples taken on August 8 displayed color stratification in the constable tube. The upper white layer was composed principally of single blue-green algal cells and small fragments of blue-green algal colonies. The middle light green layer was principally blue-green colonies and many celled filaments or larger fragments of these filaments of *Aphanizomenon, Anabaena,* and *Gloeotrichia.* In addition, there were numerous single blue-green cells and some colonial greens with a few diatoms. The lower dark layer was predominately blue-green algae, because of their abundance in the sample, but diatoms were heavily concentrated. The large-celled *Lyngbya birgei* was most concentrated in this layer, as was the dinoflagellate, *Ceratium.*

The packed cells, or residue, from the constable tubes were washed in distilled water and were dried and ignited in a platinum dish. The following results were obtained:

	Mg. dry Wgt./L			Mg. Ash/L			Mg. Vol. Sol./L		
Sta.	7-25C	8-8C	8-8N	7-25C	8-8C	8-8N	7-25C	8-8C	8-8N
1	9.8	14.6	11.8	4.4	6.8	3.0	5.4	7.8	8.8
2	10.6	14.4	8.6	5.4	4.6	2.0	5.2	9.8	6.6
3	4.8	6.4	7.2	2.0	2.8	1.2	2.8	3.6	6.0

C—Centrifuged sample N—Net plankton Vol. Sol.—volatile solids

Segments of lake bottom core samples may be analyzed microscopically to determine the diatom composition of the layered segments. To examine diatomaceous sediments in lake bed core sediments, an aliquot solids sample based on a packed volume of a selected core segment is oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) are added, the mixture cooled, washed into a centrifuge tube, and water added. The sample is washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue is then diluted to a specific volume of water (200 ml. per gram of original sample), then 2 drops of liquid household detergent are added, the sample is stirred, and 2 drops of sample are withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover slip is evaporated to dryness on a hot plate. Following drying the hot plate temperature is increased to 350° F, a clean microscopic slide is placed thereon, and a large drop of suitable microscopic mounting media such as Harleco* or Styrax* is placed on the slide. After 10 minutes, with slight cooling, the cover slip with the dried sample is inverted onto the mounting medium drop and pressed firmly into place. The slide is then examined for diatom skeletons.

Reporting

Reporting of the findings is equally as important as any other aspect of problem solving. A report represents the end product of the investigation. It is often the only link between the field investigation, which may take considerable time, money, and effort, and the public or particular report recipient. A report often recommends corrective actions to abate a problem, and these abatement efforts are necessary for the advancement of society. Thus, the report may be the most important part of a particular investigation, particularly because of the effect that it can have on broad political changes that may be focused on a problem area.

A report has certain basic yet essential features. The first of these is the title page, or cover, listing the author(s) and the responsible agency or where the report may be obtained. The title should not be too long but it should identify precisely the report contents. The second feature involves the summary, conclusions, recommendations and predictions, which are usually placed near the front of the report for ease in finding and value in display. The third basic component involves the report narrative, which includes the display of data, such as charts and figures and the discussion. The last is the report appendix.

The report *introduction* should describe briefly the problem and its location, the study objectives, the inclusive dates of the investigation, the authority for the study, and by whom the study was performed. It may relate briefly the methods used to conduct the study, but generally such descriptions should be placed in the appendix, particularly when they are lengthy and include nonstandard ones. The introduction is often placed near the front of the report, and is followed by the summary.

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* Mention of commercial products does not constitute endorsement by the Federal Water Pollution Control Administration.

The summary, conclusions, recommendations, and predictions may be the only parts of the report that are read by many of the report audience. These sections represent a condensation of the entire study; they should be drafted with great care.

When not preceded by the introduction, the first paragraph within the *summary* should introduce the study and should identify what was studied, where the study took place, who made the study and when, and what the study objectives were. The summary should briefly and concisely relate how the study was accomplished and what was found in the investigation. The entire summary should be as brief as possible and yet contain these essential facts. Stringent review and editing should always be employed. The summary should contain those particular facts that will be used to formulate conclusions. The language of the summary should be specific, and numerical data to substantiate or explain particular statements should be given where appropriate.

The *conclusions* should be concise, positive, lucid statements that relate what may be concluded from the summarized data and other observations. There is often a difference of opinion among report writers regarding the numbering of thoughts or paragraphs within the conclusions. From the standpoint of conciseness and adherence to a particular thought, it is helpful to number conclusions in consecutive order, at least initially. After these have been edited and re-edited the numbers may be removed without harm to the text material. Many writers prefer to retain the numbers. The report narrative and the data it contains must support the conclusions. The conclusions in turn must support the recommendations, and each recommendation should have a supporting conclusion.

Recommendations should be preferably numbered in consecutive order and developed with great care and sound logic. Recommendations represent the groundwork towards abatement or problem correction.

Predictions may or may not be within the investigation's objectives. They are of great value to the report's reading audience, however, to ascertain that water quality which is expected to be attained when all recommendations are met, when 50 percent or 30 percent of the recommendations are completed, or if no action is taken as a result of the investigation. Such predictions might well follow that section of the report devoted to recommendations.

The narrative within the report body supports the summary, conclusions, and recommendations. Its structure can be enhanced, and omissions avoided, by a carefully prepared outline listing all necessary items in logical continuity.

The *area description* section should include a general area location map, as well as a specific map of the study reach showing stations sampled, principal population centers and principal waste sources. Background information on municipal and industrial development and land use is helpful here.

The *water uses* section describes in informative detail those uses associated with:

(a) Municipalities,
(b) Fish propagation and production,
(c) Recreation,
(d) Industrial water supply,
(e) Navigation,
(f) Irrigation, and
(g) Hydropower.

Monetary damages resulting from existing or predicted water quality associated with these uses, and benefits from recommendations made should be noted where possible.

The *waste sources* section discusses wastes entering the waterway including:

(a) Municipal,
(b) Industrial, and
(c) Agricultural.

Measured or computed waste loads to specific stream reaches, with itemized particular wastewater constituents where possible, should be ascribed to each major waste source described specifically and separately.

The *effects of pollution on water quality and uses* include the findings of fact and their discussion, analyses and interpretation. This is the report section that bears the major burden of support for the conclusions and recommendations. Its principal discussions center around various water quality standards and specifically bacterial pollution, aquatic life in all its many facets, and aesthetic considerations. Featured within this section are data display and data interpretation.

Organizing the data entails graphs, photographs, and tables. Here a spark of ingenuity and imagination will reap great rewards. Often a report is "sold" by the manner in which data are organized and presented. Data first are arranged in tables. Lengthy, detailed tables should be placed in the report appendix—if placed in the narrative, they detract from reading coherency. Easy-to-follow summary tables, prepared as a digest of the tabulated data in the appendix, are helpful in the narrative to explain and substantiate discussion and conclusions.

Relationships among particular components within the data or trends among stream reaches of particular water quality components may be shown as graphs. Graphs should be uncluttered, pertinent, and easy to follow. Broad lines to illustrate trends are preferred. Should the reader wish to verify a particular value at a given point, he will consult the detailed tables. Graphs should "picture" important information and be used sparingly only to underscore principal points.

In developing a report, do not say that certain information may be found in Table X or Figure Y, because this type of statement does not give the reader any vital information. Rather, make a positive factual statement using pertinent data within the sentence to substantiate the statement, and refer to the appropriate table or figure parenthetically as a source to substantiate the data used and to gain additional information. Interpret for the reader. Do not expect the reader to interpret tabular data or figures without help from the report narrative. It is always the readers prerogative to agree or disagree with the writer's interpretations.

Data interpretation gives meaning and vitality to the report. Interpretation is a clear statement of what is meant by what was found.

What is the problem?
Why is it a problem?
What is the cause?
What are the effects?
What corrections can be instituted?
Where should these be made?
When should corrections be initiated, and completed?

Data interpretation includes an evaluation of visible observations, of factors such as the physical drift of organisms into the sampling station from a tributary or an area unaffected by pollution, and of organism population trends throughout the study reach. Other studies often are cited to substantiate the writer's findings or to show that other investigators have found similar, or different, phenomena under comparable circumstances. Citations from other works should be adequately and correctly referenced. Unless the report is a literature search, literature citations should be reserved for important points that can be made more positive or more clear with additional clarification or substantiation from an outside source.

The report *appendix* is the proper recipient of long or complex tables, charts or tables listing scientific names, discussions of methods or procedures, descriptions of special studies performed to ascertain particular facts described in report narrative, and elaborate calculations. These materials should not detract from the reading of the report narrative by being placed within it.

An appropriate report cover should be designed that will wrap the package suitably to present to the reader.

The writer should read aloud his report to ascertain illogical approaches and flaws in rhythm. This procedure may be the greatest aid to self-editing. Good technical writing is clear and concise and omits needless words. The specific word should be chosen instead of the general, the definite word instead of the vague, the concrete word instead of the abstract. Qualifying words should be avoided! Rarely is there more than one proper word to express a particular idea. A discriminate writer will search for that word, and when it is found he will profit thereby.

Finally the report should be submitted to an associate whose judgment is respected for review (Mackenthun, 1969). When a report is submitted to a reviewer, both writer and reviewer assume certain specific obligations. The writer should submit his report for review only after completing his own revision as discussed.

The writer has an obligation to inform the reviewer of the report's purpose and its expected audience. Is the purpose of the report to inform generally? To establish a specific fact in the literature? To establish policy? To interpret data? To serve as a basis for conference or litigation in resolving a particular problem? Will the audience be the general lay public, people technically trained in the report's subject, or will it represent a mixture of several technical skills and varied interests?

The writer is obligated to:

(a) Strive for the best in manuscript preparation, placing it in final form as talents permit;
(b) Be meticulous about data accuracy, grammar, punctuation, and spelling;
(c) Develop the report for the reading level of the report's audience;
(d) Forward a minimum of two manuscript copies to each reviewer —it may be desirable for the reviewer to retain one and return one with comments in the report margin to the writer; and
(e) Avoid writing down everything that has been done with the expectation that their viewer will cut, organize, and reconstruct the manuscript.

The writer should prepare himself mentally for critical review comments. Remember, the reviewer usually attempts at all times to be helpful and constructive. A "no comment" reviewer most likely has not fulfilled his obligation and is of no help to the writer.

A proper review entails consideration of the technical message, as well as the manner in which the message is presented. A review can be editorial only, but rarely can a technical review disregard the editorial aspects. Good grammer and technical competence usually are inseparable. A technical reviewer reads a document for clarity, technical accuracy, and to determine whether a dual meaning is present in the written word:

The reviewer is obligated to:

(a) Consider the purpose the report is designed to fulfill;
(b) Be constructive, thorough, and helpful with comments;

(c) Be certain of his own accuracy in suggesting changes;

(d) Base comments on the technical level and interests of report audience;

(e) Avoid sarcasm, argument, or destruction of the writer's style for the sake of expression in the reviewer's words; and

(f) Appreciate that the purpose of the review is to help the writer produce a better report.

Demonstrations

Following a field study with its report including conclusions, recommendations, and predictions, there is urgent need to ascertain the correctness and value of those recommendations and predictions. Assuming that the proffered recommendations are feasible technically and monetarily, their value should be demonstrated through appropriate action. Far too many studies are terminated with a report. Technical advancement can best be made by effecting sound and logical demonstrations to determine the correctness of particular recommendations and predictions. Through time, and using the investigative report and implemented demonstrations as a basis of fact, future investigators can adapt and modify their recommendations and predictions to answer future problems in an improved manner.

5

ORGANIC WASTES

USING selected portions of past field investigations as examples, it will be shown in this and succeeding chapters how various water quality constituents can affect aquatic life and how this type of information can be presented to those not intimately familiar with the biological discipline.

Menominee River

In early August 1963, a field study, limited to 12 days, was made on the Brule and Menominee rivers separating Michigan from Wisconsin.* The Brule River rises in northern Wisconsin near the eastern edge of a popular recreational area dotted with many natural lakes. It flows through Wisconsin in an easterly direction becoming the boundary between Michigan and Wisconsin. Downstream the Brule joins the Michigamme River to form the Menominee River, which continues as the states boundary flowing in a southeasterly direction for about 115 miles to the Menominee, Michigan-Marinette, Wisconsin, area where it enters the Green Bay arm of Lake Michigan (figure 18).

The Brule and Menominee rivers pass through a gently rolling, thickly wooded valley, which exhibits a restful scenic beauty. The virgin white pine forests of the valley, which once provided a major national source of white pine lumber, have largely been replaced by the attractive quaking aspen, interspaced with groups of a variety of conifers and an occasional hardwood.

The cool, swift waters of the upper reaches of the Brule River provide an ideal habitat for trout; the warmer waters of the Menominee support sturgeon, walleye, bass, bluegill, and other sport fishes. Between Florence, Wis., and the Memominee-Marinette area there are eleven dams that im-

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*** Report on Pollution of the Interstate Waters of the Menominee and Brule Rivers, Michigan-Wisconsin, by A. W. West, K. M. Mackenthun, L. E. Keup and F. W. Kittrell. U.S. Department of Health, Education and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, November 1963.**

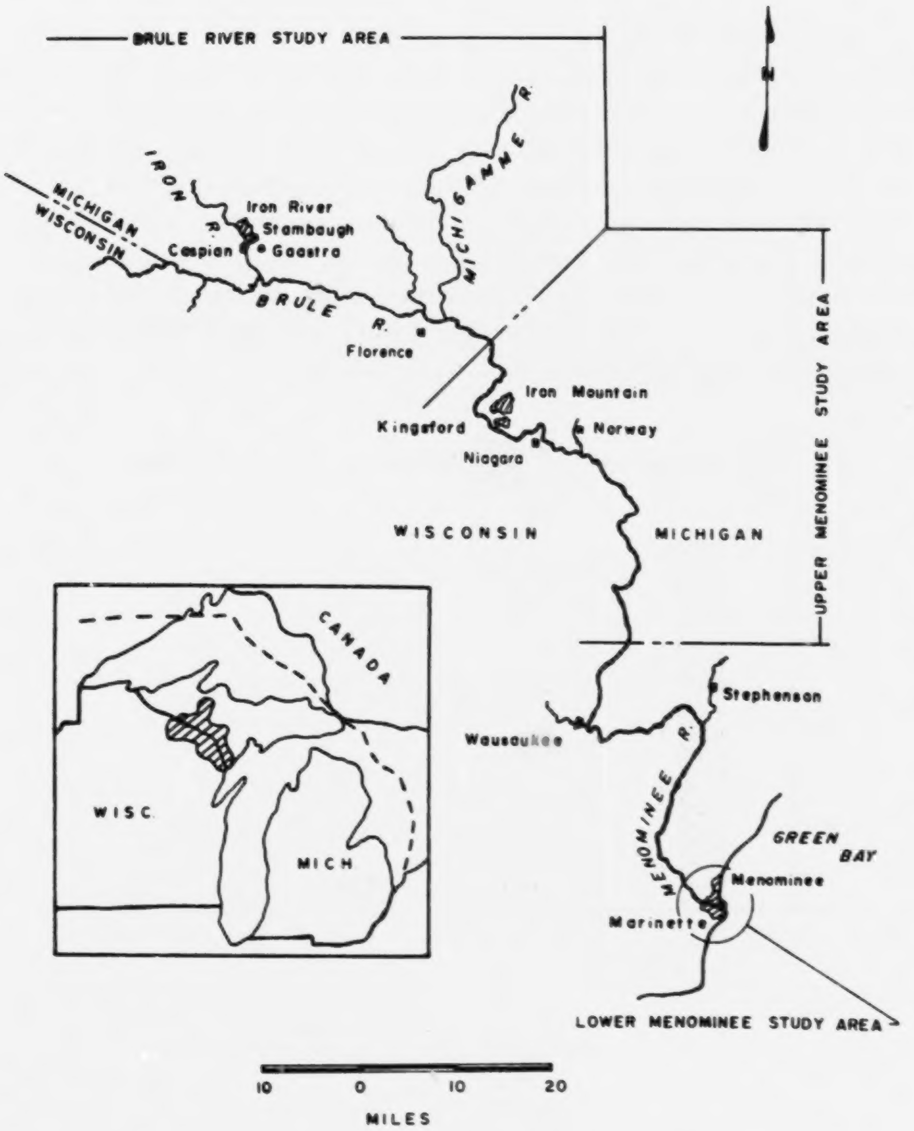
BRULE RIVER STUDY AREA
N
IRON R.
Iron River
Stambaugh
Gaastra
Caspian
MICHIGAN
WISCONSIN
BRULE R.
Florence
MICHIGAMME R.
Iron Mountain
Kingsford
Norway
Niagara
WISCONSIN
MICHIGAN
UPPER MENOMINEE STUDY AREA
CANADA
WISC.
MICH
Stephenson
Wausaukee
MENOMINEE R.
GREEN BAY
Menominee
Marinette
LOWER MENOMINEE STUDY AREA
10
0
10
20
MILES

Figure 18. Location map for the Brule and Menominee Rivers, Wisconsin-Michigan.

pound run-of-the-river pools on the Menominee River. During the 12 days of the survey, the mean daily river discharges averaged 300 cubic feet per second (c.f.s.) at the mouth of the Brule River, 1,200 c.f.s. in the upper Menominee River and 1,400 c.f.s. in the downstream reaches of the Menominee. In addition to sewage effluent representing various degrees of treatment, the rivers received pollutants from important industrial operations including iron ore, pulp and paper, and organic chemicals.

The Brule River received from its tributary, the Iron River, the acid mine drainage from four iron mines and the effluents from four municipal sewage treatment plants. About 1 year prior to the study the Iron River had received gross acid mine drainage pollution.

The Brule River stream bed was composed of rock, rubble, and gravel with occasional sand. The current was swift and water depths ranged from 6 inches to 2 feet in areas sampled. Samples of stream bed associated organisms were collected in a 20-mile stream reach. Findings indicated that conditions upstream from the confluence of the Iron and Brule rivers were adequate to support a bottom organism community that is typically associated with unpolluted water including stoneflies, riffle beetles, mayflies, and caddisflies. Downstream from this confluence, many organisms sensitive to adverse conditions were reduced drastically in population while those organisms that were able to secure their food supply

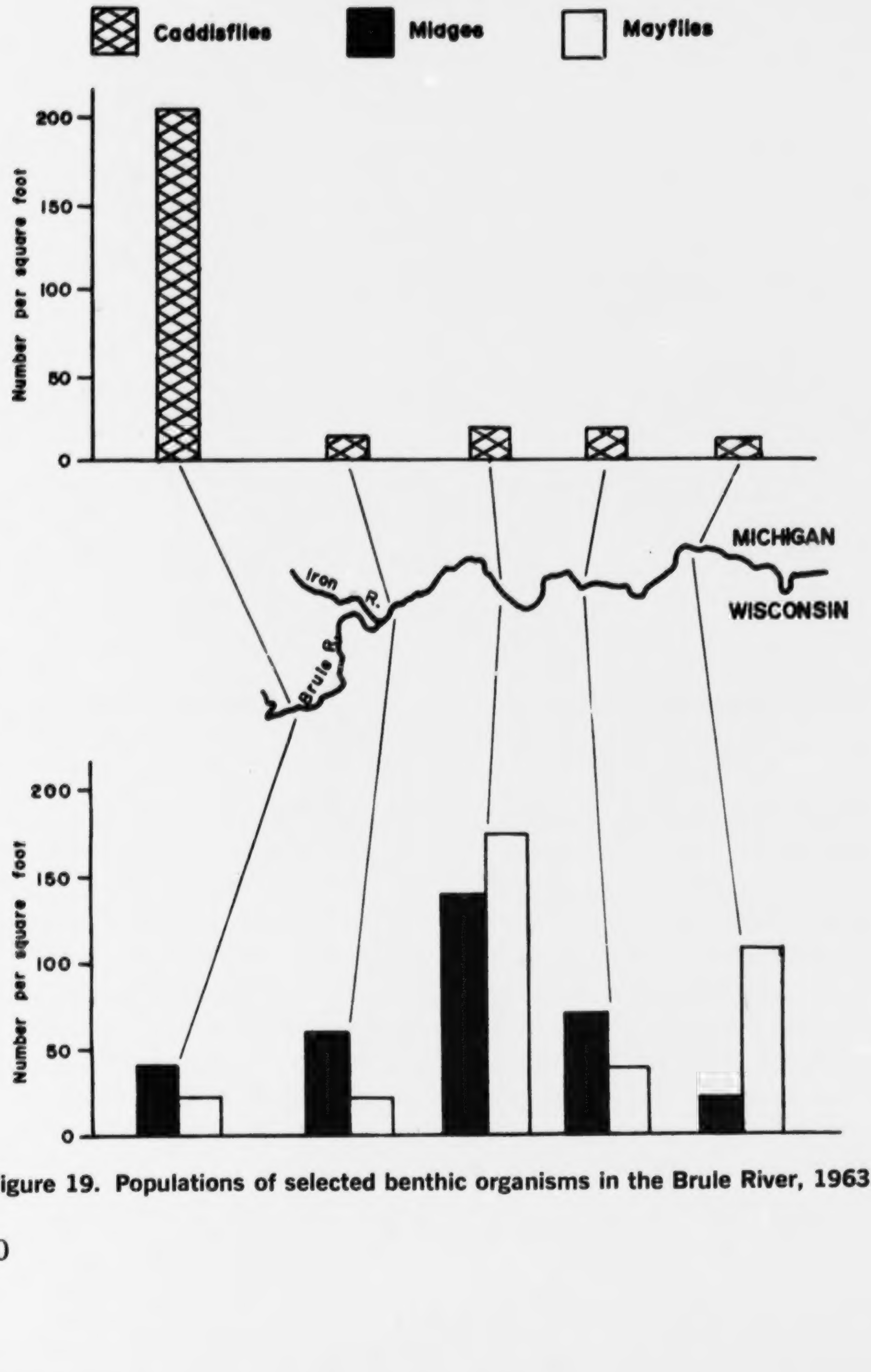

Figure 19. Populations of selected benthic organisms in the Brule River, 1963.

while living in close association with a dense growth of filamentous green algae prospered in numbers (figure 19).

In the Kingsford-Iron Mountain, Mich., area, samples for bottom associated organisms were taken at river mile 96.4, 200 yards downstream from the sewage treatment plant, and in Upper Quinnesec reservoir at mileage 93.7 (figure 20). Upstream from the organic waste source, there was a balanced bottom dwelling community with many organisms sensitive towards pollution and relatively few tolerant sludgeworms or other organism types that tolerate and thrive in organic wastes (figure 21).

In the biological data display for this report, three very broad organism classifications were used. These consisted of those sensitive organisms including immature stoneflies, caddisflies, mayflies, riffle beetles and hellgrammites; those organisms very tolerant towards organic wastes including sludgeworms, several species of midges with ventral blood gills, the pond leech *Helobdella stagnalis* (Linnaeus), and worm-like organisms that are associated closely with this group; and a large group of organisms

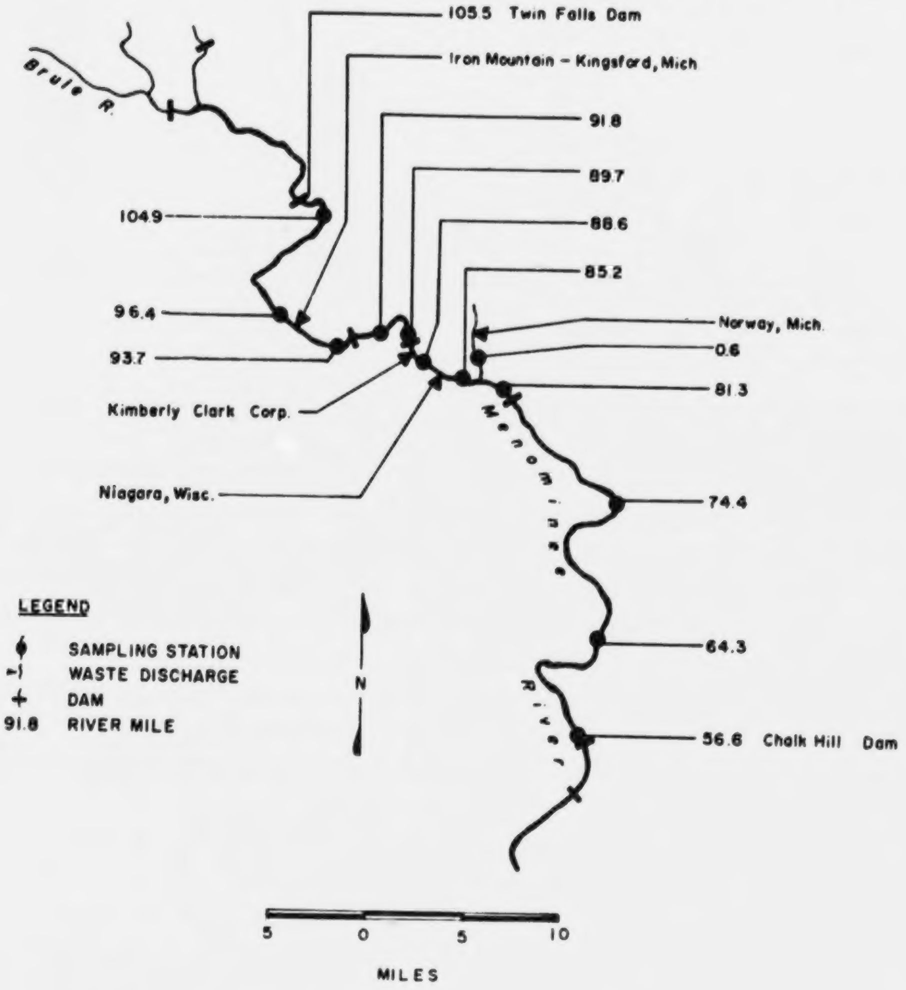
105.5 Twin Falls Dam
Iron Mountain – Kingsford, Mich
Brule R.
91.8
89.7
104.9
88.6
85.2
96.4
Norway, Mich.
0.6
93.7
81.3
Kimberly Clark Corp.
Menominee River
Niagara, Wisc.
74.4
LEGEND
SAMPLING STATION
WASTE DISCHARGE
DAM
91.8 RIVER MILE
N
64.3
56.6 Chalk Hill Dam
5
0
5
10
MILES

Figure 20. Sampling station location map for the Menominee River.

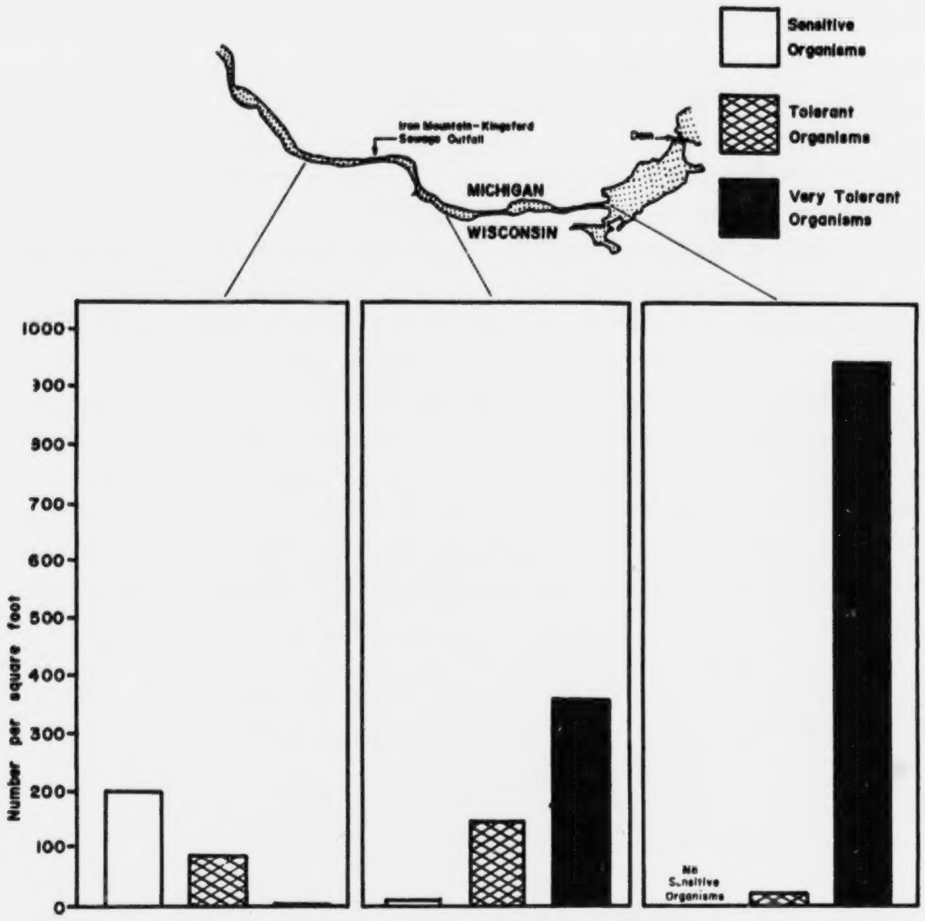

Figure 21. Bottom organism populations—Iron Mountain-Kingsford area, Menominee River, August, 1963.

that are termed tolerant because they are not now known to fit either of the other two groups.

The display of biological data in the aforementioned manner is very effective because the dramatic environmental change in the very few stream miles from a point upstream from the waste source to the uppermost reaches of a receiving reservoir is largely self-evident (figure 21). The clean water associated forms decreased from a plentiful population that would furnish food for an abundant fish population to zero in three successive stations. Likewise, pollution tolerant organisms increased at the same three stations from barely discernible numbers to 950 per square foot, which is representative of a waterway bed covered with organic sludge.

To ascertain effects on sluggish water environments from Niagara, Wis., area pollution, bottom samples were collected from two reservoirs bracketing the area at river miles 89.7 and 81.3 respectively (figure 22). The population of bottom associated organisms found in the uppermost reservoir was considered typical for a clean water environment with a well diversified organism complex containing caddisflies and mayflies. The or-

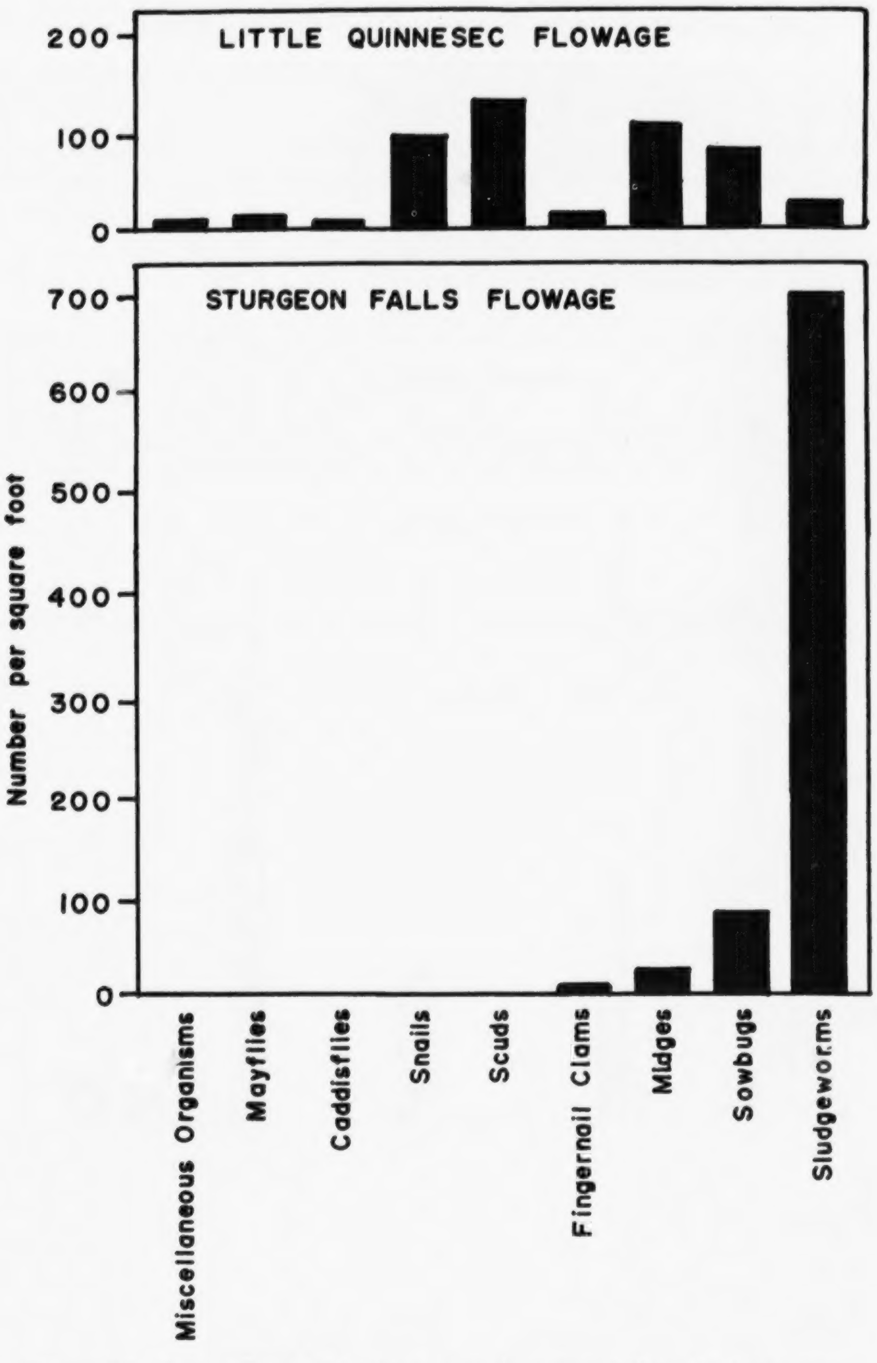

Figure 22. Comparison of bottom organism populations in two upper Menominee River reservoirs.

ganism assemblage in the Sturgeon Falls reservoir downstream was one depicting a polluted environment. Sensitive forms were eliminated; pollution tolerant forms were greatly increased compared to the upstream reservoir. Sludge and wood chips were found in areas of reduced current; wood fibers and slime bacteria were present.

Surber (1957) conducted a survey of lake reports and found that

". . . an abundance of tubificids in excess of 100 per square foot apparently truly represented polluted habitats." After more than a decade, this interpretative observation still seems sound.

That portion studied in the Lower Menominee River encompassed just slightly more than 3½ miles. An unpolluted environment was indicated at the upstream sampling station where sensitive burrowing mayflies were plentiful (figure 23). Downstream from the first organic waste source a

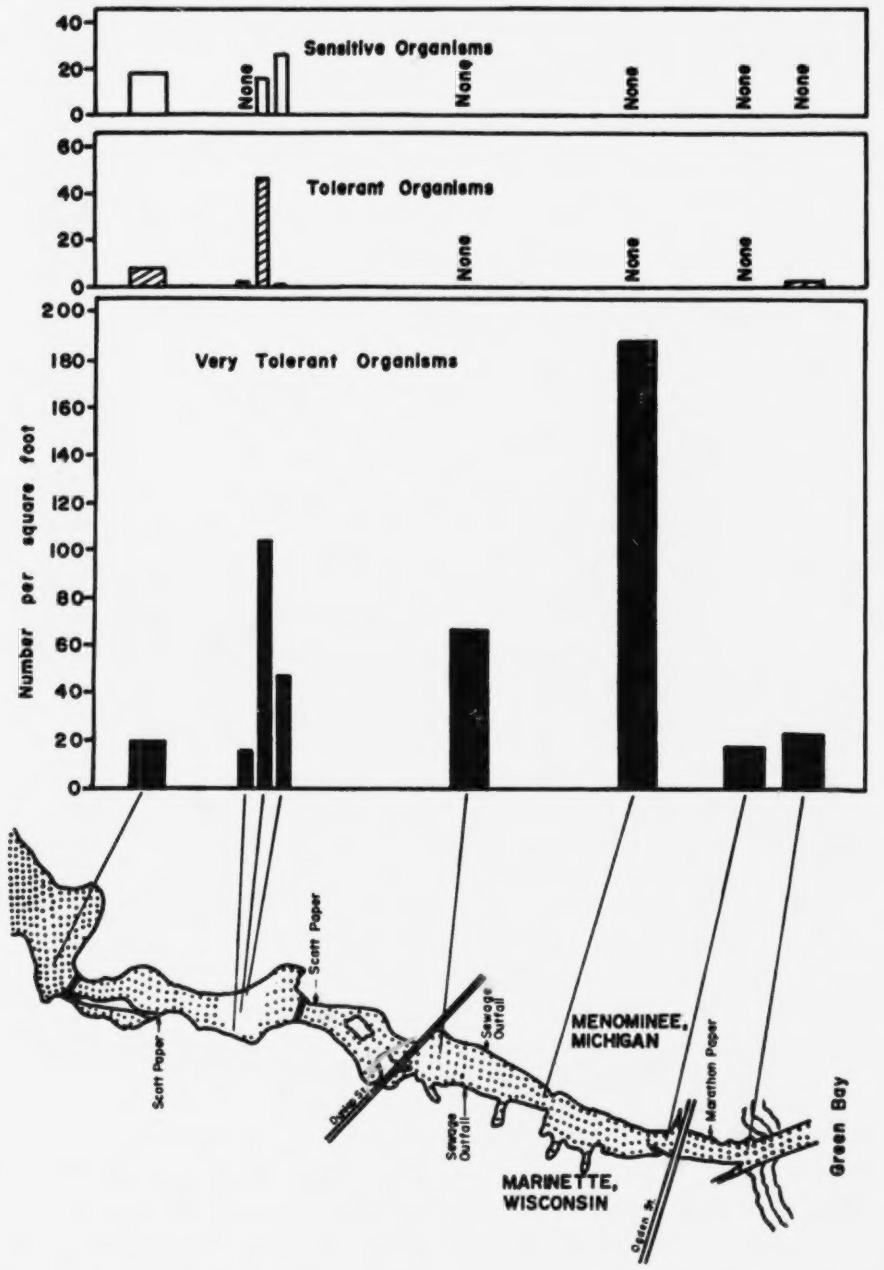

Figure 23. Populations of bottom associated organisms, lower Menominee River, August, 1963.

polluted habitat was found on the waste source side and a habitat only slightly defiled was found near the opposite bank, because of waste channeling in the receiving stream. Downstream from the waste source, sludge deposits, wood chips, wood fibers, and slime bacteria occasionally boiled to the surface as a mass, creating an unsightly and odoriferous condition, gradually dispersing and sinking at some point downstream to reform a sludge deposit and extend, physically, the zone of active decomposition.

When pulp and paper wastes had become fully mixed with the receiving waters, sensitive clean water organisms were eliminated from the polluted habitat as were those in the intermediate tolerant group. Only the pollution tolerant sludgeworms and bloodworms were found among wood chips, fibers, and slimes. The population of these increased downstream from sewage treatment plant waste sources, but decreased markedly downstream near the river's mouth because of toxic components within the sludge.

It is to be noted that in figures 19, 21, 22, and 23, biological data are presented clearly and concisely, and in a form that a layman can understand readily. The figures are not cluttered with too much detail and the bars in graphs are broad and easily distinguishable one from another to permit easy recognition of population trends and broad, significant differences among sampling areas. Data depicted for a particular station represented the average of samples taken at that station.

Blackstone River

The Blackstone River begins in the southern part of Worcester, Massachusetts, and flows in a southeasterly direction for 42 miles to Pawtucket, R.I., then southerly for 7 miles to its mouth at the Seekonk River. Principal tributaries include the Mumford and West Rivers from Massachusetts, and the Branch River from Rhode Island. Water quality data were obtained from field studies conducted during March and August, 1964.*

The Blackstone River drains an area of 540 square miles; its fall averages about 10 feet per mile. Formerly it tumbled over many rocky rapids, but these have long been buried beneath impoundments to create power. The first use of the water power of the Blackstone took place in 1671 and by the early 1700's many grist and sawmills were furnished power by low head dams in the basin. Some of these dams have been abandoned, but more than 30 still exist.

The most significant types of wastes in the Blackstone River drainage area are municipal sewage and woolen textile wastes. At the time of the survey, the river was receiving biochemical oxygen demanding sewage wastes from a population equivalent to 93,000 persons. Forty-three percent of this organic load was introduced where the stream was relatively small near its headwaters, and where wastewater impact on aquatic life would be expected to be most noticeable. Recreational use and all fishery pursuits were severely limited because of organic pollution.

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* Report on Pollution of Interstate Waters of the Blackstone and Ten Mile Rivers, Mass.-R.I. K. M. Mackenthun, A. W. West, R. K. Ballentine, and F. W. Kittrell. U.S. Department of Health, Education, and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, January 1965.

The suitability of the Blackstone River to support aquatic life at the time of the study was dramatically illustrated in figure 24 and 25 where the low organism diversity in upstream reaches corresponded with high populations of pollution tolerant organisms, principally sludgeworms. Near the river's headwaters, sludge deposits, oily substances, and slime growths supported over 20,000 sludgeworms per square foot. The sludge worm population increased in numbers following the introduction of sewage treatment plant wastes and then gradually decreased downstream as stream self-purification took place. Before the population could be diminished to a reasonable level (less than 100 per square foot) another source of organic waste was introduced to boost again the sludgeworm population. At river mile 22 (figure 25) a tributary carrying variously colored wool fibers and other materials introduced toxic materials into the Blackstone River that reduced bottom organism populations. Extensive sludge deposits, floating balls of fibers that were microscopically identified as being wool impregnated with grease, and slimes on bottom materials were observed.

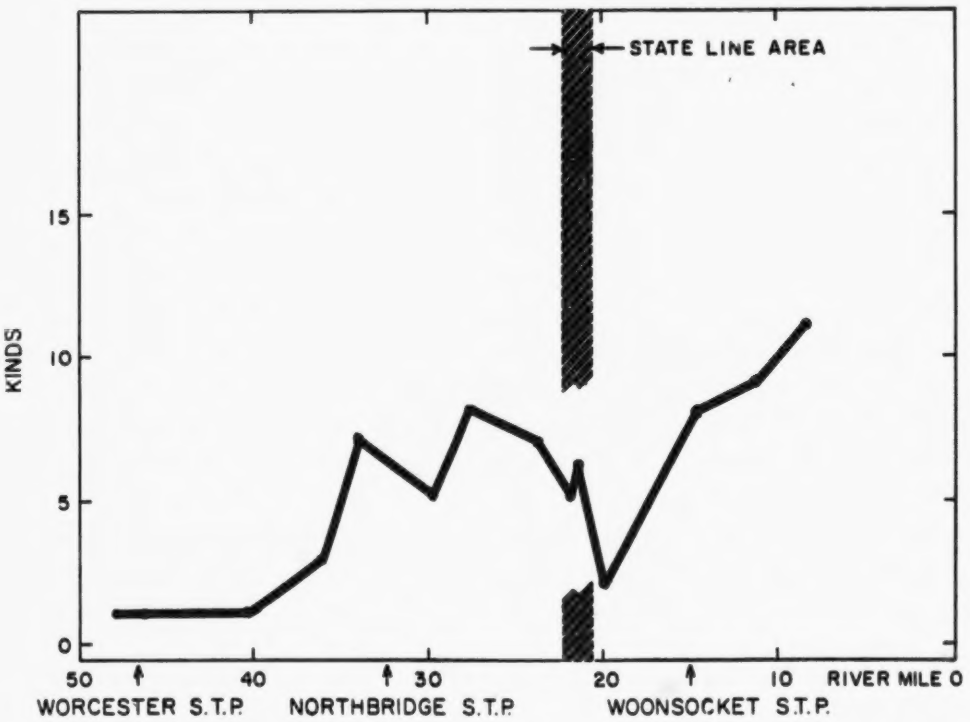

Figure 24. Kinds of bottom organisms, Blackstone River, August, 1964.

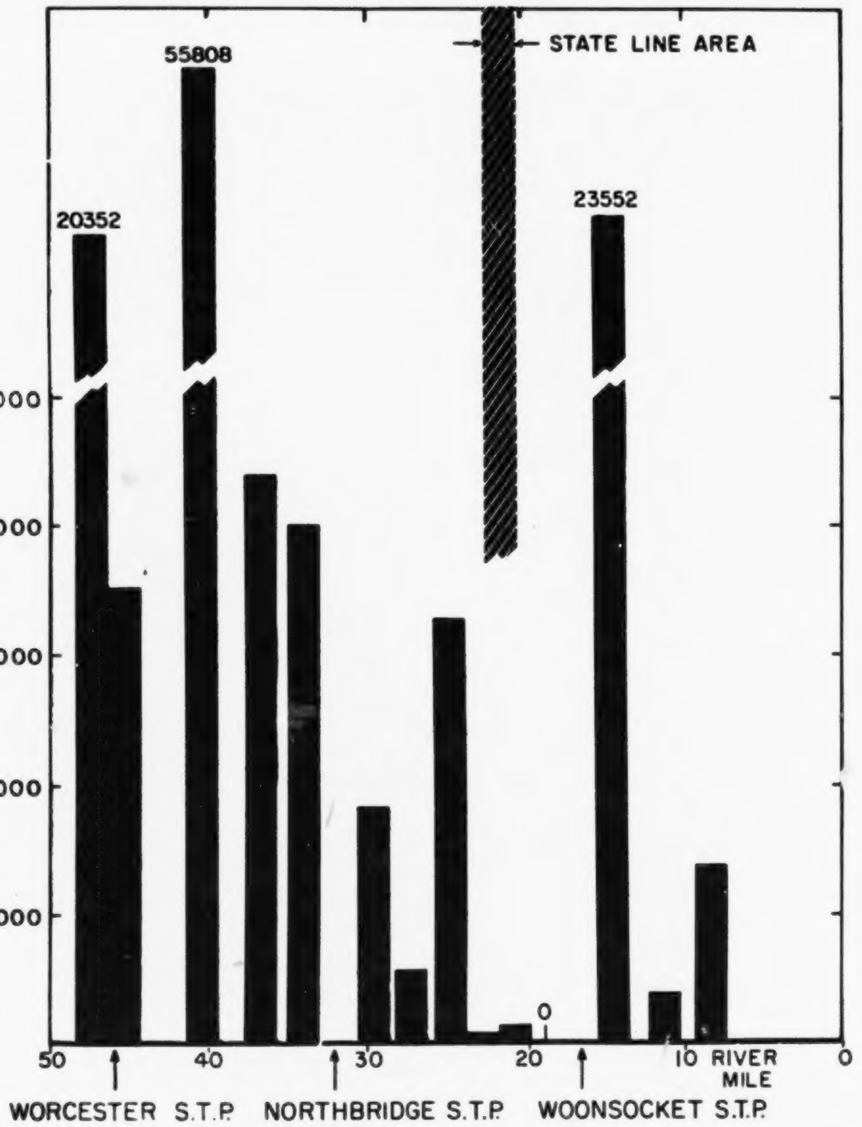

Figure 25. Numbers of pollution-tolerant bottom organisms per square foot, Blackstone River, August, 1964.

Wisconsin River

An intermittent 11-year biological study of the stream bottom life of the Wisconsin River, Wis., indicated no marked differences in bottom conditions at a given station among any of the years under investigation.* Prolific growths of filamentous bacterial slimes occurred in several stream reaches during both summer and winter periods. Unsuitable bottom habitats for organisms were created because of severely decreased dissolved oxygen and the blanketing effects of settleable solids and bacterial slimes. The area studied extended from mile 360 to mile 190 (figure 26).

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* Mackenthun, K. M. 1961. The Impact of Pollution Upon Stream Biota in the Wisconsin River. 19 pp., mimeo.

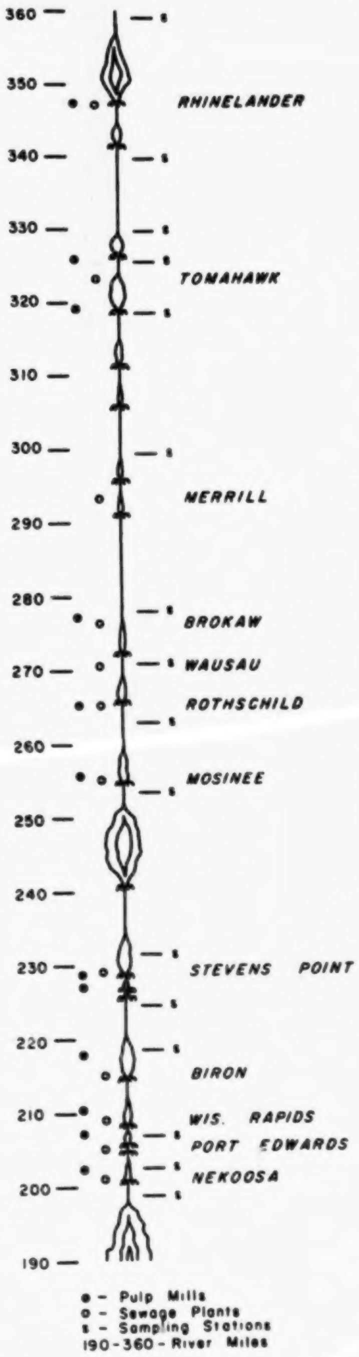
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
RHINELANDER
TOMAHAWK
MERRILL
BROKAW
WAUSAU
ROTHSCHILD
MOSINEE
STEVENS POINT
BIRON
WIS. RAPIDS
PORT EDWARDS
NEKOOSA
● - Pulp Mills
o - Sewage Plants
s - Sampling Stations
190-360 - River Miles

Figure 26. Wisconsin River profile with mileage designations, pollution sources, and sampling stations.

The long-term average flow for the several stations of record on the Wisconsin River is shown on the dilution chart (figure 27). The 50 percent duration value for the section under consideration ranges from slightly less than 1,000 c.f.s. at Rhinelander to slightly more than 3,000 c.f.s. at Nekoosa. Other things being equal, a given load discharged to a stream

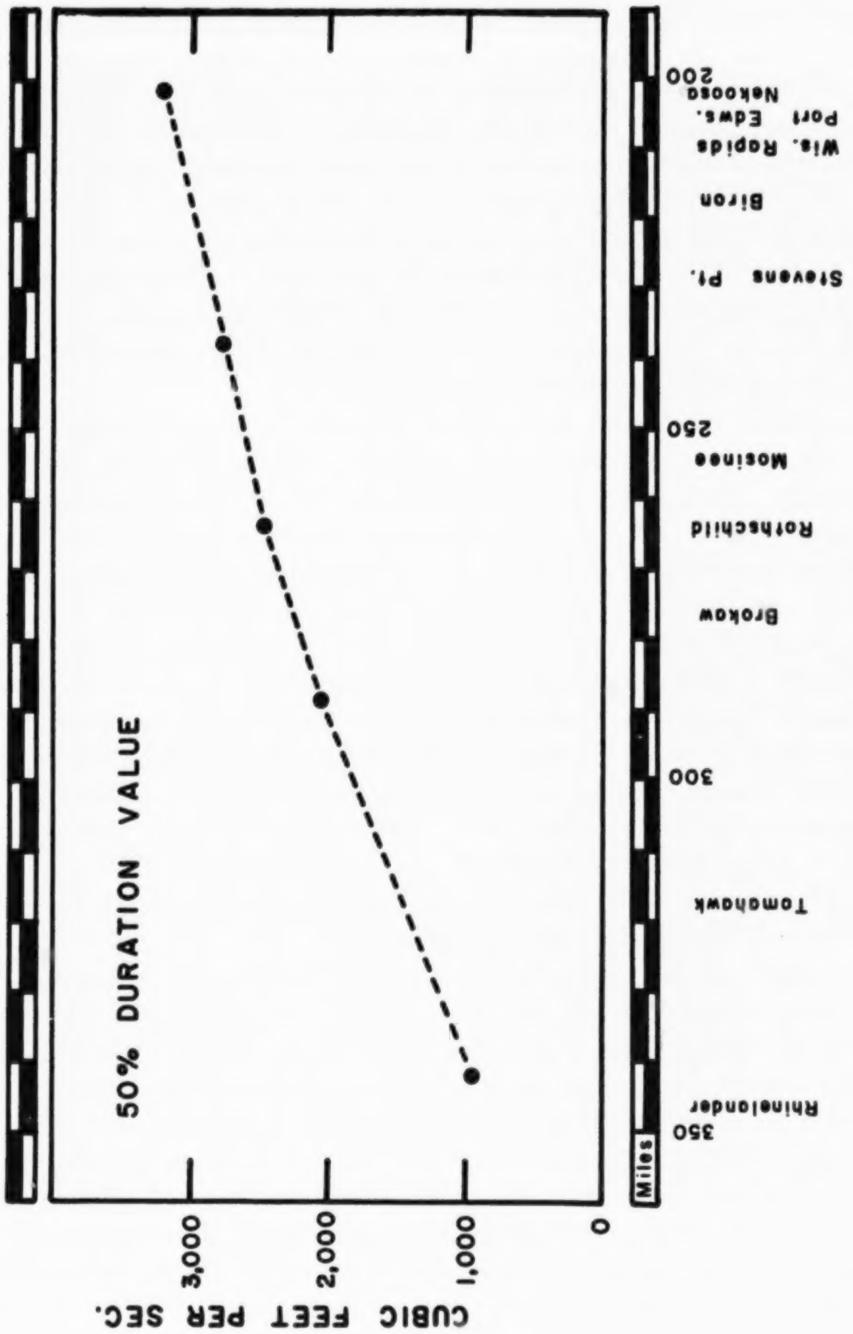

Figure 27. Wisconsin River Dilution Chart

having, for example, a 2,000 c.f.s. flow has the same degradation effect as one-half of the hypothetical load discharged at a point in the stream having only 1,000 c.f.s. flow.

Stream bed samples were collected both in August and in March under ice cover. March data indicate no intolerant (sensitive) bottom fauna downstream from Rhinelander, Wis., for a distance of about 50 miles (figure 28). A similar paucity of sensitive organisms existed downstream from Brokaw for a distance of about 45 miles. Along with the species abundance shown as the number, the relative population abundance in number per square foot and the population characteristic shown as the percentage of the population abundance were depicted in this chart. Much can be said for such a presentation from the standpoint of careful interpretation of graphic materials, but the presentation is somewhat cluttered with too much detail and is difficult for the general reader to follow. Indeed, the August data were presented in similar fashion for 5 years for the entire river reach studied and the results of this presentation attempt precluded suitable reduction to picture here.

In general, the March biological data showed a slight reduction in bottom organism species abundance and some reduction in the population abundance. There was a general tendency to have a greater proportion of the population comprised of very tolerant forms. Especially in the areas upstream from Merrill and Brokaw, a reduction was noted in both species number and population abundance of the clean water forms. These two areas were influenced by the effects of upstream pollution during the winter months with a subsequent growth of filamentous bacteria that covered the bottom formations. Consequently, these areas fluctuated between periods of degradation in the winter and recovery during the summer. Thus, sampling beneath the ice in late winter showed that the zone of active decomposition had moved downstream from the source of organic pollution during winter. A stream reach that appeared unpolluted during summer supported growths of *Sphaerotilus* and associated bacteria with a reduction in sensitive organisms during winter.

A slightly earlier (1958) effort to display some of the same data was even more complicated, graphically (figure 29). A tremendous amount of data are shown in this figure: Stream mileages, major cities, location of dams, location of pulp and paper mills, organism numbers, percentages of sensitive, tolerant, and very tolerant organism numbers, zones of pollution, and variations among 4 years of sampling! Depicting the stream zones of pollution has merit for public interpretation providing sufficient explanatory material is presented. But, it is difficult, if not impossible, to present so much information graphically in clear understandable fashion on one page–interpretation would be challenging even to the professional.

South Platte River

Wastewaters entering the South Platte River in Denver, Colo., are of mixed origin.* They come from municipal treatment facilities, industries,

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* From "Effects of Pollution on the Aquatic Life Resources of the South Platte River Basin." South Platte River Basin Project, Denver, Colo., and Technical Advisory and Investigations Branch, Cincinnati, Ohio, Federal Water Pollution Control Administration, U.S. Department of the Interior, December 1967, prepared by Lowell E. Keup.

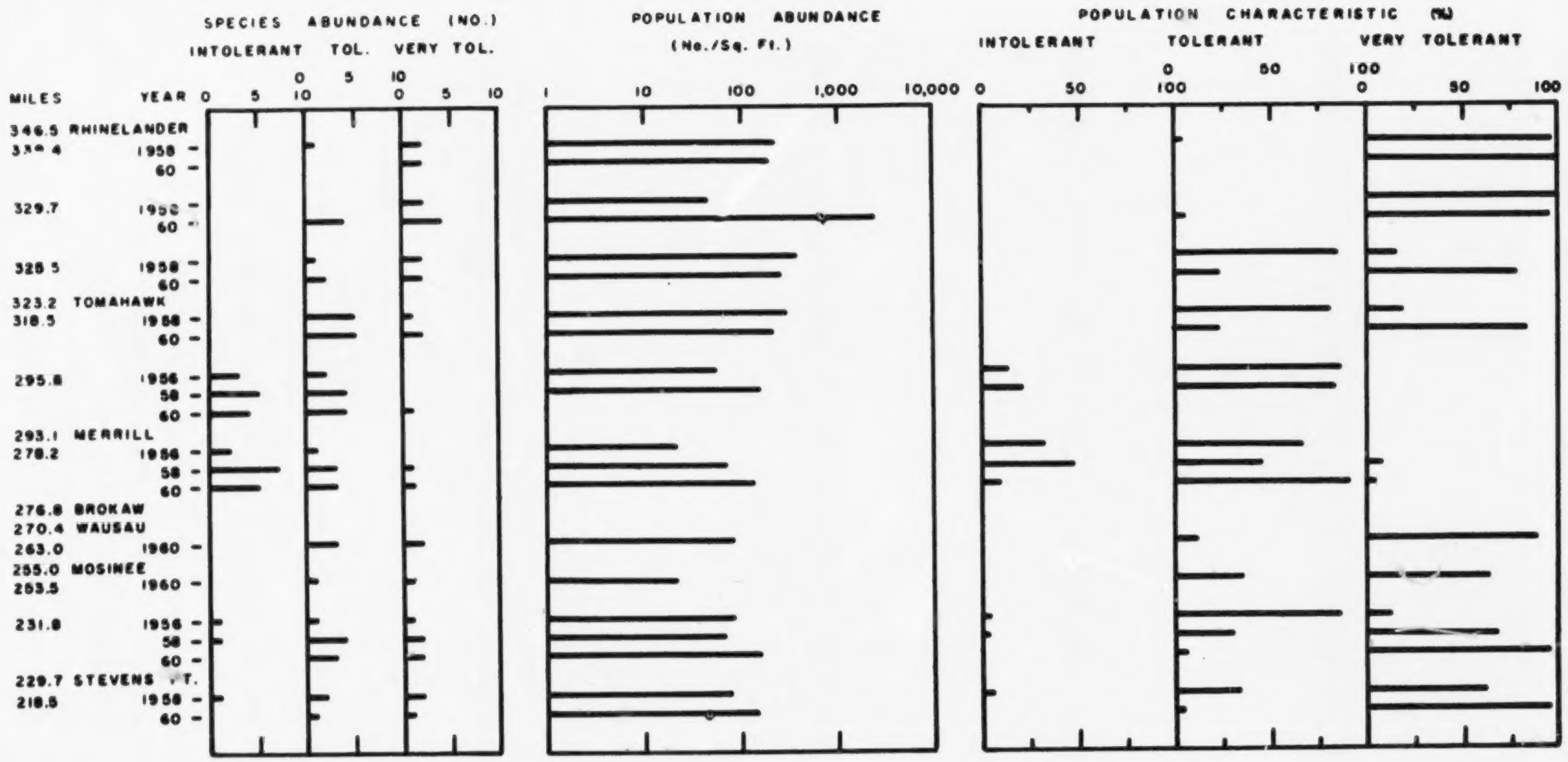

Figure 28. Wisconsin River bottom fauna—March data.

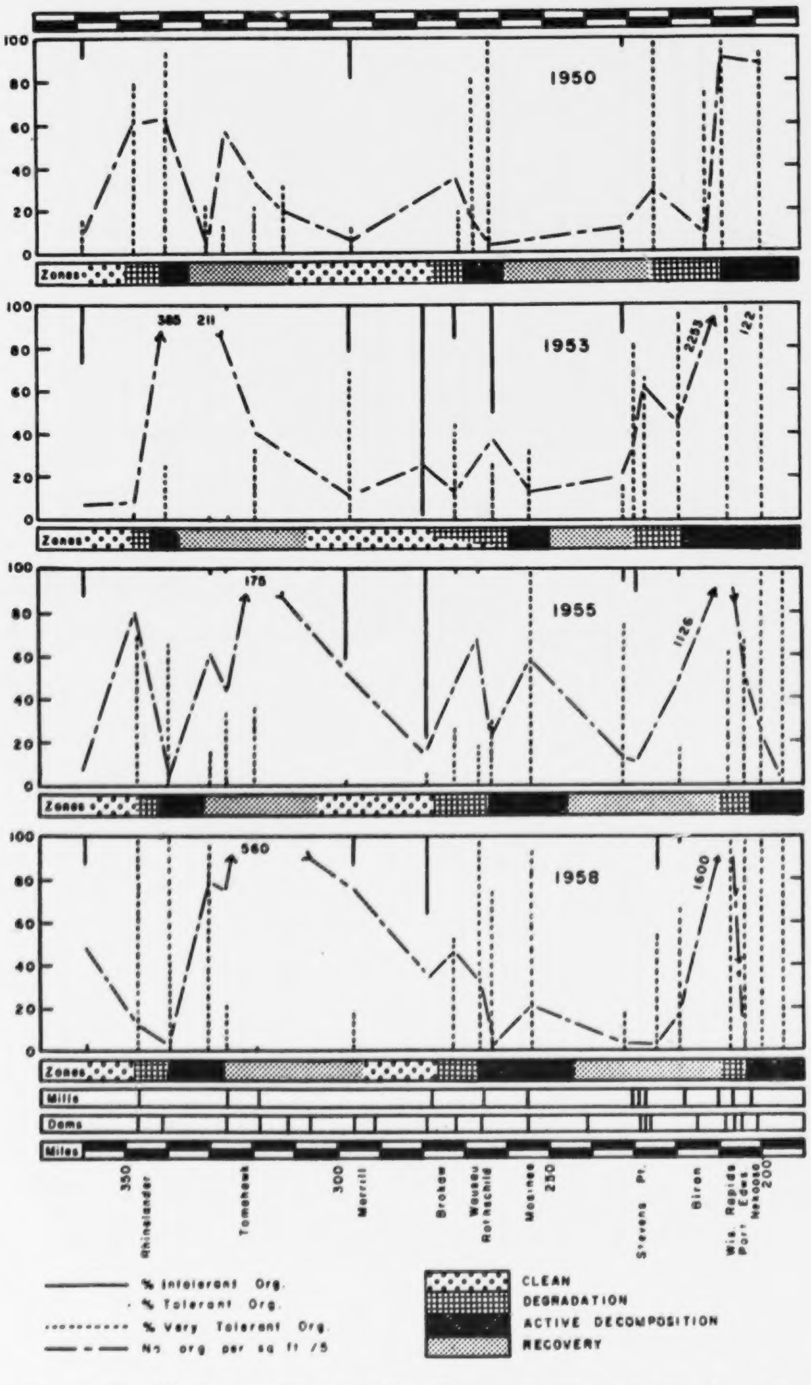

Figure 29. Biotic conditions in the Wisconsin River during August.

cattle holding pens, storm sewers, and polluted tributaries. The major pollutant is organic solid materials, both suspended and settled. Other pollutants are present, but their effects are masked by the preponderant organic materials.

Excessive quantities of organic wastes, undergoing rapid decomposition, alter the chemical characteristics of the waterway by producing large quantities of sulfides, methane and other products of decomposition, and by reducing the quantity of dissolved oxygen. The settleable solids settle to the stream bottom forming organic rich sludgebeds that "blanket" the original bottom of gravel, rubble, or soil thereby altering the physical environment. These chemical and physical changes are not tolerated by sensitive organisms such as the aquatic stages of stoneflies, mayfies, and caddisflies, that are found in unpolluted habitats. Surviving pollution tolerant animals, such as sludgeworms, bloodworms, leeches and sewage flies increase in numbers because of a lack of competition from the eliminated forms. Sludgebeds may produce a large increase in numbers because they increase the habitable area and the available food for these "aquatic manure worms." Pollution may become so severe that even these relatively tolerant forms may be reduced in numbers or eliminated. Figure 30 illustrates the elimination of sensitive bottom animals and the rapid increase in the population of pollution tolerant organisms in May as the river enters the city of Denver. In August, 1964, near the confluence of Cherry Creek and at Platteville sludgeworm numbers were 38,000 and 19,500 per square foot, respectively.

During May and August, from the York Street bridge downstream to Fort Lupton, Colo., pollution by decomposing organics was severe enough to reduce pollution tolerant organisms (figure 30). At Franklin Street, the large quantity of decomposing organic material sufficiently lowered water quality so that even pollution tolerant organisms were eliminated. Here, the stream bed was covered with sludges, estimated at 45,000 tons wet weight, which were obviously rotting cow manure and undoubtedly originated from the cattle holding pens along this river reach.

After flowing 40 miles, the river recovered enough to allow large numbers of pollution tolerant sludgeworms and bloodworms to reappear in the bottom sludges at Platteville, Colo. (figure 30). In August large red patches of sludgeworms (19,500 per square foot) could be seen here on top of the sludge deposits. Filamentous slime growths were less extensive than they were upstream. Within a short distance from Platteville, much of this polluted water was diverted for irrigation and the areas downstream from here were influenced more by pollution from local sources than from the Denver Metropolitan Area.

East Pearl River

A diverse population of bottom fauna was found in the East and West Hobolochitto creeks and in Farr's Slough upstream from pollutional effects from Picayune, Miss., on the East Pearl River.* At one station, more than 40 species of bottom fauna were found (figure 31). Down-

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* From Report on Pollution of Interstate Waters of the Pearl and East Pearl Rivers, L.-Miss., U.S. Department of Health, Education, and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, and Region IV Office, Atlanta, Ga., September 1963.

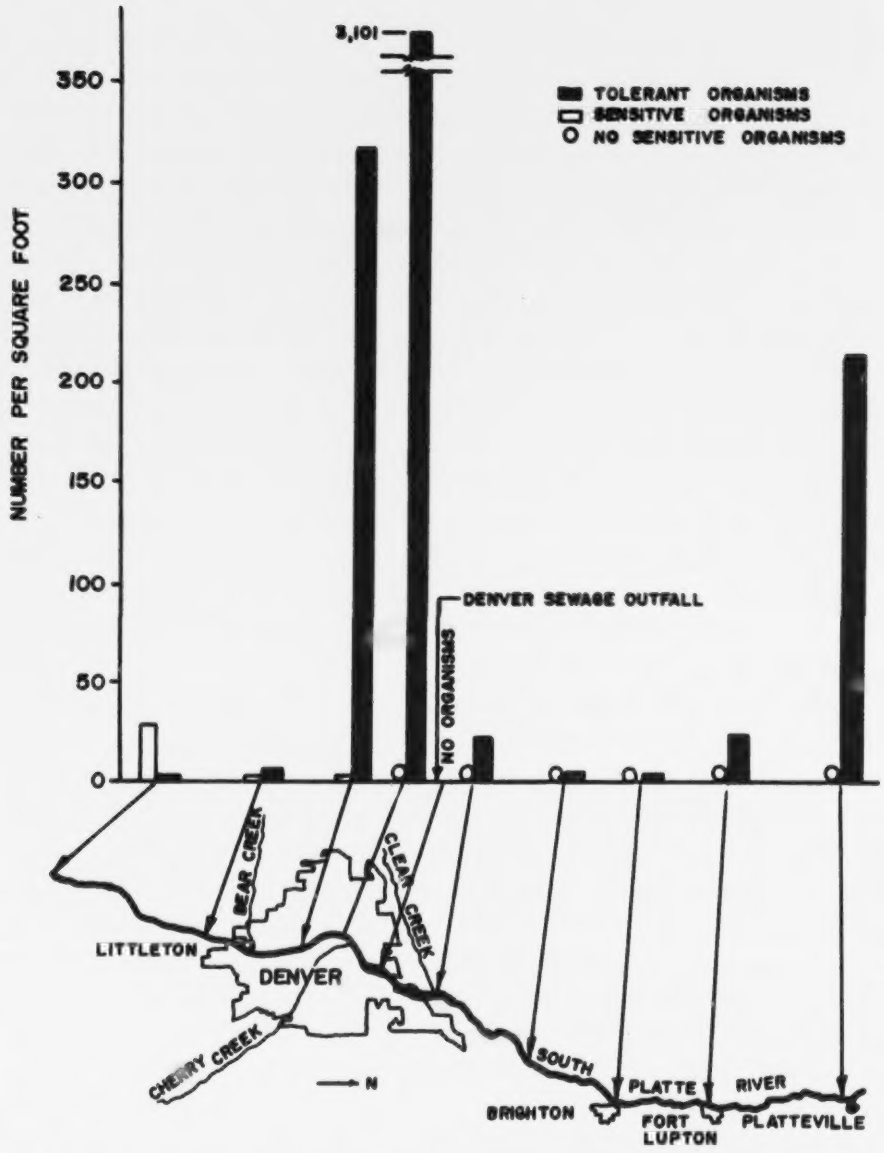

Figure 30. Populations of bottom animals, South Platte River, Denver Metropolitan Area, May, 1964.

stream from Picayune, and the discharge of a chemical company, biological samples showed distinct adverse effects from pollution on the stream bottom. Species numbers were reduced to four in this reach compared to upstream reaches where more than 10 and often 20 species were found. Pollution tolerant sludgeworms and blood worms increased here, sensitive mayflies and caddisflies were absent but were plentiful at upstream stations, and bacterial slimes were obvious on higher aquatic plants and other supporting objects. The stream recovered rapidly and samples from stations downstream indicated a fauna rich in diversity again.

In late September, 1962, the chemical company discharged wastes toxic to aquatic life and a severe fish kill resulted that extended for at least 17

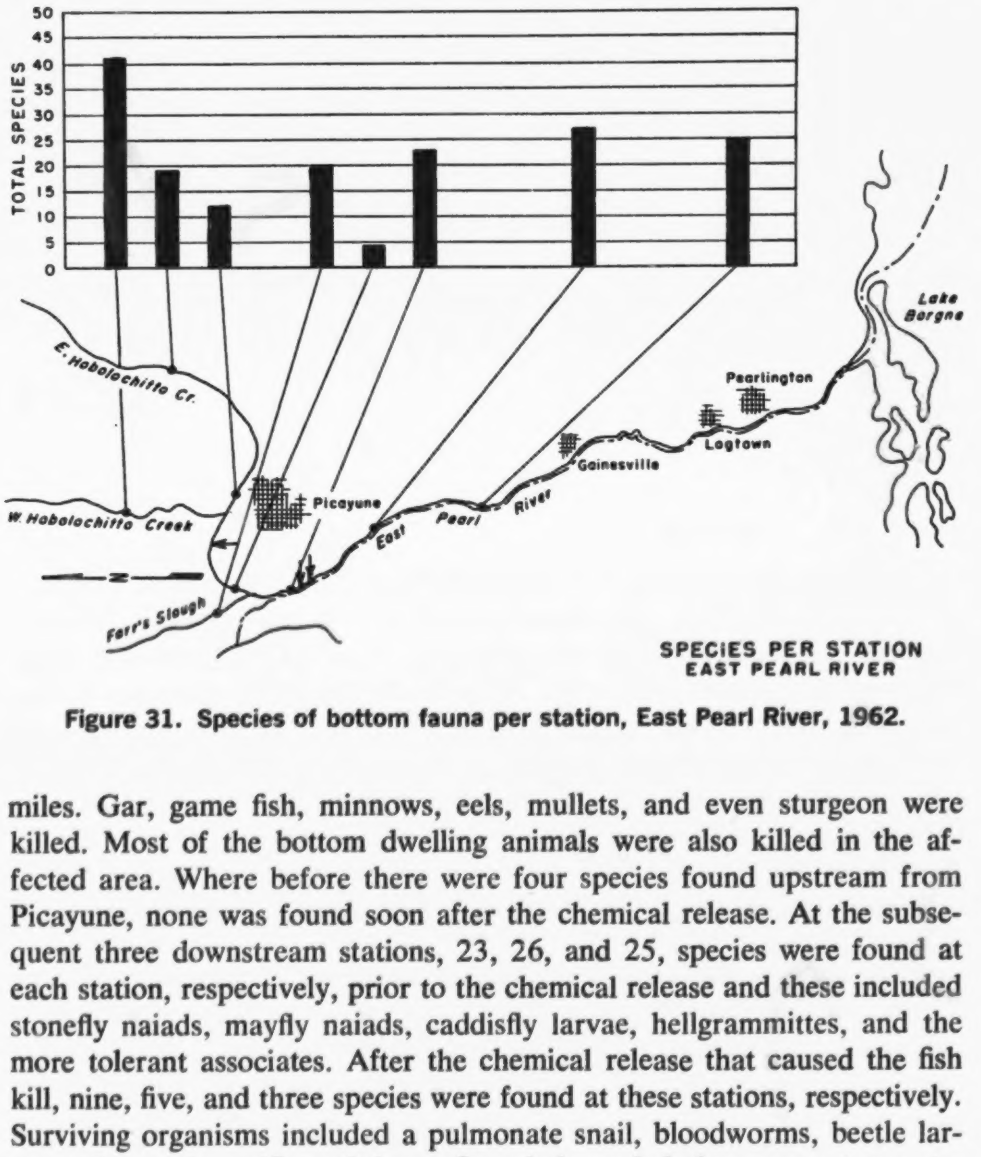

Figure 31. Species of bottom fauna per station, East Pearl River, 1962.

miles. Gar, game fish, minnows, eels, mullets, and even sturgeon were killed. Most of the bottom dwelling animals were also killed in the affected area. Where before there were four species found upstream from Picayune, none was found soon after the chemical release. At the subsequent three downstream stations, 23, 26, and 25, species were found at each station, respectively, prior to the chemical release and these included stonefly naiads, mayfly naiads, caddisfly larvae, hellgrammittes, and the more tolerant associates. After the chemical release that caused the fish kill, nine, five, and three species were found at these stations, respectively. Surviving organisms included a pulmonate snail, bloodworms, beetle larvae, tolerant damselfly and dragonfly naiads, and sludgeworms at one station. Toxic materials are considered in greater detail in Chapter VII.

6

SILTS

Coosa River System

THE Coosa River, formed by the confluence of the Etowah and Oostanaula rivers in Rome, Ga., flows westerly across Georgia into Alabama (Figure 32). Etowah River investigations began just downstream from Allatoona Dam near Cartersville, Ga.; they extended downstream to the confluence with the Oostanaula River in Rome, Ga., and continued in the Coosa River to Lake Weiss, Ala.*

Process wastes from mineral, chemical and textile industries, and raw domestic sewage were discharged to the Etowah River in the vicinity of Cartersville, Ga. During the August survey, silts from mining operations were carried downstream into the Coosa River and across the Georgia-Alabama State line.

In the upstream Etowah River study reach, flow was 300 c.f.s. for about 17 hours of the day; it climbed rapidly to a 7,300 c.f.s. peak at 12:15 p.m. and subsided again for the next 6 hours according to Allatoona Dam turbine operating schedules. Just upstream from the mouth of the Etowah River, flows ranged from 700 to 4,500 c.f.s. Flow in the Oostanaula River in Rome normally ranged between 800 and 1,000 c.f.s. except for an early morning low when the water surface elevations at the mouth were influenced by peak Etowah River flows. The more regular undulating flow pattern in the Coosa River reflected the combined flow characteristics of both the Etowah and Oostanaula rivers and ranged from about 2,000 to 4,600 c.f.s. diurnally.

The dominant pollution discharged to the Etowah River was silt. One ore processing company discharged 500 tons of mineral washing waste solids per day to the river a short distance downstream from Allatoona Dam. Other sources of silt pollution included road bank erosion and soil erosion.

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* Report on Coosa River System, Georgia-Alabama. U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, January 1963.

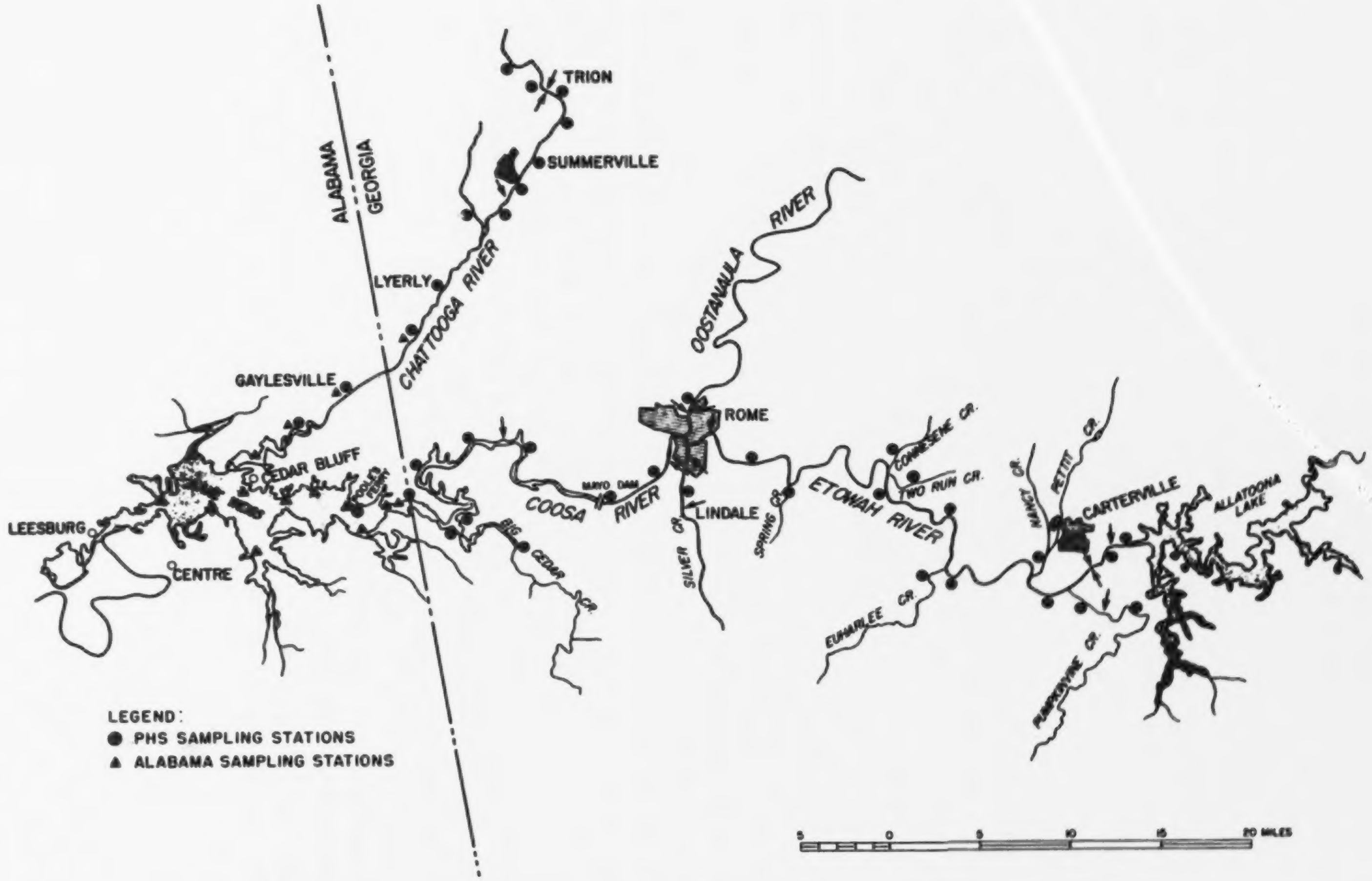
TRION
SUMMERVILLE
ALABAMA
GEORGIA
LYERLY
CHATTOOGA RIVER
GAYLESVILLE
CEDAR BLUFF
LEESBURG
CENTRE
OOSTANAULA RIVER
ROME
MAYO DAM
COOSA RIVER
LINDALE
SILVER CR.
BIG CEDAR CR.
SPRING CR.
ETOWAH RIVER
CONNESENE CR.
TWO RUN CR.
EUHARLEE CR.
NANCY CR.
PETTIT CR.
CARTERVILLE
ALLATOONA LAKE
PUMPKINVINE CR.
LEGEND:
● PHS SAMPLING STATIONS
▲ ALABAMA SAMPLING STATIONS
5
0
5
10
15
20 MILES

Figure 32. Location map and sampling stations on Coosa River system, Alabama-Georiga.

The color and turbidity in the Etowah River increased sharply around 11:30 a.m., about one-half hour after the turbines in Allatoona Dam were opened. During the next hour, stream suspended solids increased to 900 mg./l. peaks, and the color turned deep reddish-tan as most of the waste solids, which had been deposited the previous evening, were resuspended and flushed downstream. The suspended solids concentration subsided from about 12:30 a.m. to 2:30 p.m. and remained at or below 25 mg./l. during the next 20 hours of the daily cycles. The arithmetic average from 120 samples in a 24-hour suspended solids concentration study was 52 mg./1.; this calculated to 550 tons of suspended solids per day (figure 33). The entire Etowah River downstream from Allatoona Dam and the Coosa River to Lake Weiss were kept highly turbid because of their silt pollution.

A study of stream bed organisms indicated that deposition of silt and other particulate materials on the stream bed affected the quantitative and qualitative distribution of the benthos. The processes of erosion or of mining debris deposition increased greatly the relative proportion of finer materials in the stream bed and reduced the number of usable habitats in which organisms may live. These deposits were principally inorganic, and the combined impact of deposition and the abrasive action of the sand carried by strong currents was so great that the characteristic population response to organic wastes discharged at several points was not observed, except in the reach just downstream from Rome, Georgia.

Only a few organisms, mostly sludgeworms and midges, were able to survive in the silt-laden Etowah River (figure 34). The penstock discharge, deep in Allatoona Reservoir, was very low in dissolved oxygen resulting in a bottom organism population restricted to a very few tolerant forms. *Crenothrix* and other iron bacteria deposited a reddish-brown floc over much of the vegetation and portions of the near shore stream bed. A short distance downstream, the silty mineral washing wastewaters were discharged creating a restrictive habitat for most aquatic life. Limited numbers of sensitive organisms such as aquatic stages of mayflies and hellgrammites were restricted to the few remaining shallow riffles where the effects of silt pollution were least pronounced. The Coosa River also was very turbid and the population of stream bed organisms was only slightly enhanced over that found in the Etowah River. This study again demonstrated the adverse effects of silt and sand deposition upon the biota, both in restricting species diversity and also in limiting organism production to low numbers.

The three dimensional charts used to display the data in figures 34 and 35 are not well understood by the nonprofessional report reader; they should be used with caution. There is too often the tendency to display too much data on one page with confusion the result that ends in frustration and despair for the reader making the interpretation. As with most graphs, the three dimensional presentation is most effective to illustrate a

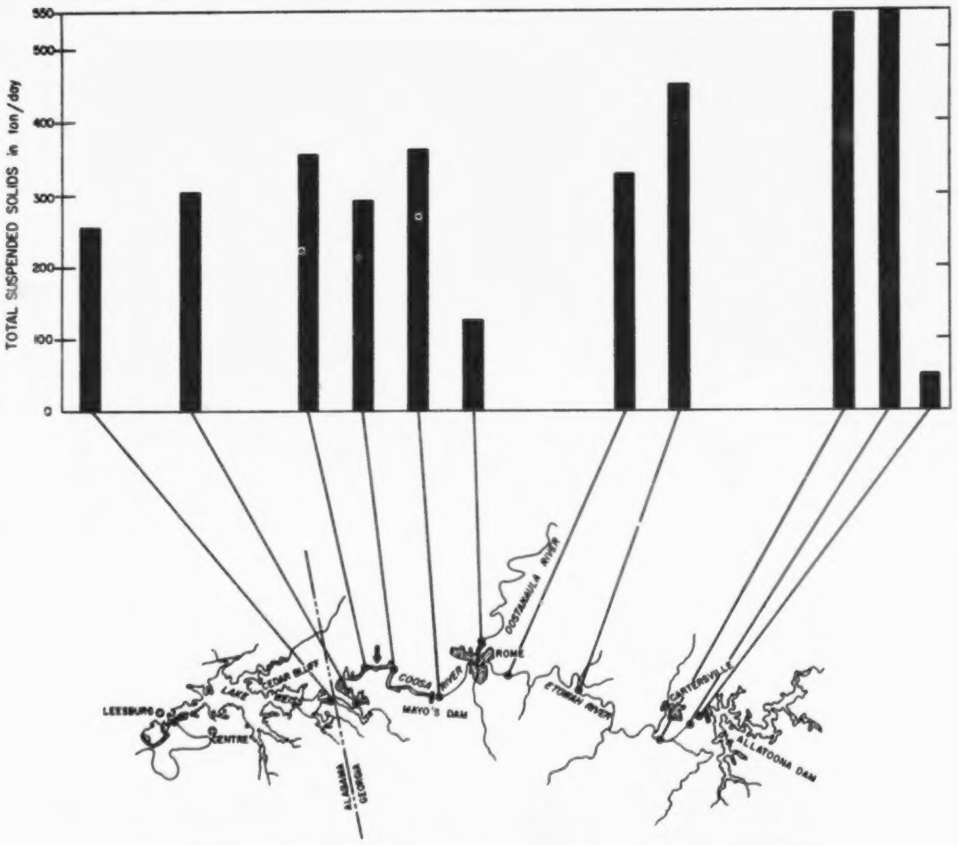

Figure 33. Total suspended solids in tons/day in Coosa River system.

minimal number of projections where trends can be noted easily without undue effort expended in interpretation. Figure 35, especially, does not meet this basic requirement.

Samples for planktonic algal determinations were collected from a depth of 2 feet at three locations in the Etowah River and four locations in the Coosa River (figure 35). A short distance downstream from Lake Allatoona, the waters in the Etowah River were very clear with 10 percent of the incident light remaining at the bottom in 60 inches. Planktonic algae had not had time to develop fully at this point. Five genera of algae other than diatoms and nine species of diatoms were found. Twenty-five miles downstream in the reach exposed to the effects of silt turbidity, the planktonic algal population was low (126 cells per ml.) and the genera of algae other than diatoms was reduced to two. Here, 1 percent of the incident light remained in only 26 inches of water. Because the algal population, which could affect light transmission through increased turbidity, was very low at this station, the low transparency was attributed to the inorganic silt load. The potential for algal development here was restricted to about 2 feet by the availability of light, and further was hampered by the adverse physical actions of sands and silts on algal cells.

The Oostanaula River, which joins the Etowah River at Rome, Ga.,

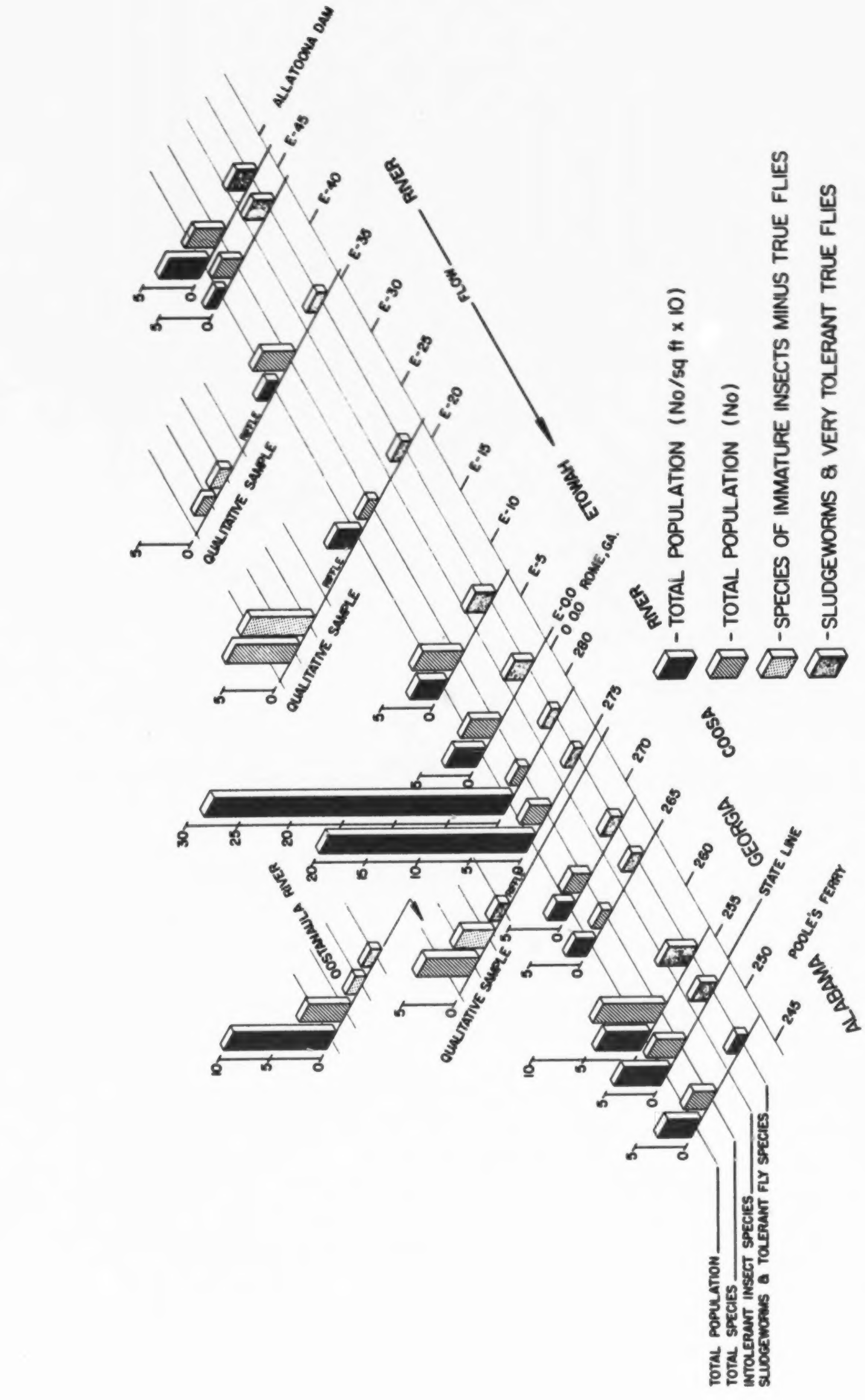

Figure 34. Population of stream bed associated organisms in Coosa River system, 1963.

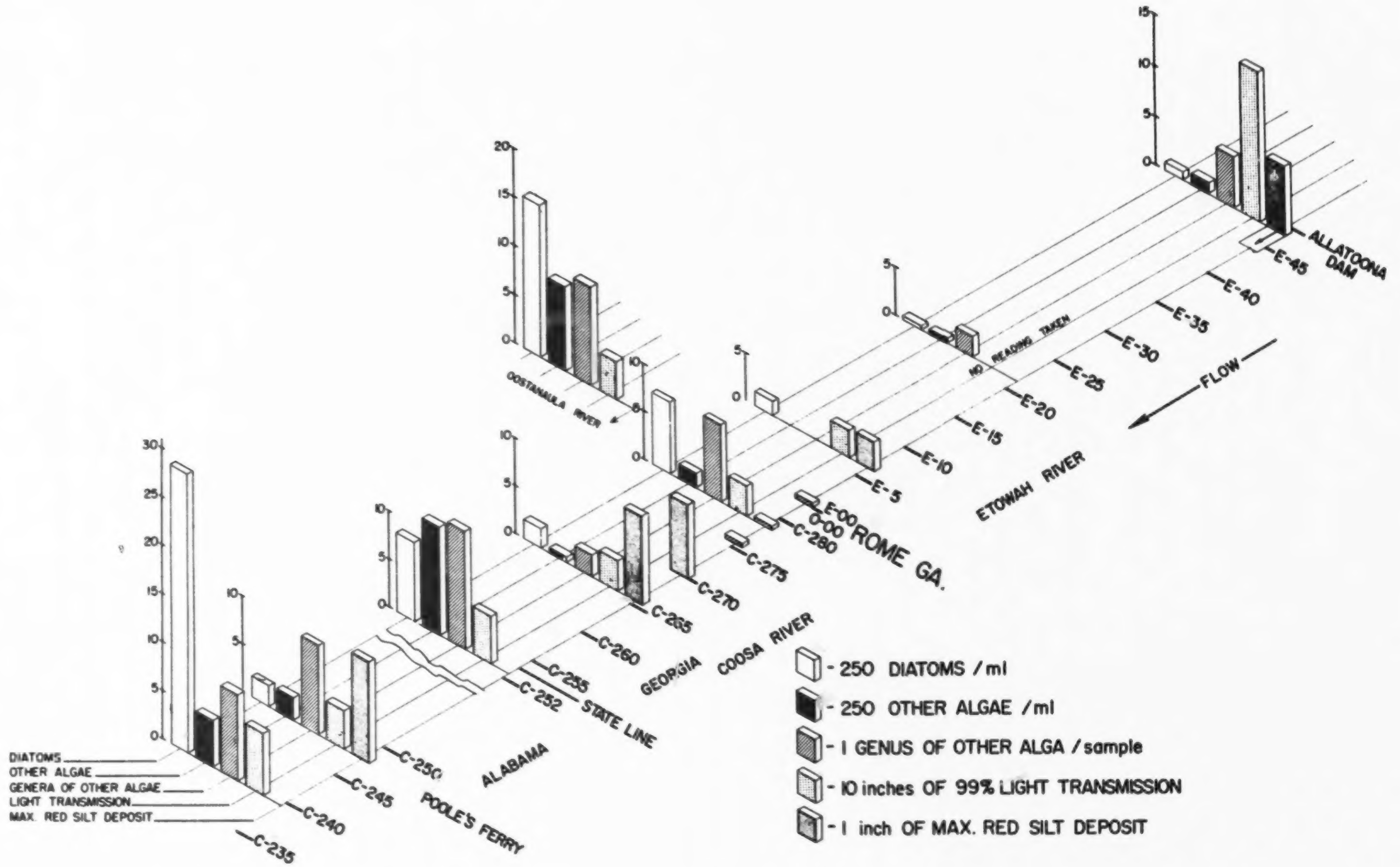

Figure 35. Algal population, light transmission and silt deposits, Coosa River system, Alabama-Georgia.

was used as a control environment unaffected by silt pollution other than land runoff. Here, the planktonic algal population was 10 times more abundant than at any place sampled in the Etowah River; 10 algal genera excluding diatoms were found.

Whenever possible, control stations should be located upstream on the same stream in which pollutional effects from waste sources are being observed. Occasionally this is not possible or practical as in the study of the Etowah River because of the presence of Lake Allatoona. In these cases, control stations may be selected on other streams within the same drainage basin and, as nearly as possible, with morphometric features similar to those of the study stream.

Light transmission was restricted in the Coosa River, and since the algal population was low, silt was the contributing factor. The depth of effective light penetration gradually increased downstream in the Coosa until at the State line 1 percent of the incident light, considered adequate for algal development, remained at a depth of 48 inches and 2.5 percent of the incident light, which is generally considered adequate for rooted aquatic plant development, remained at 37 inches.

Samples from a station near the center of Lake Weiss yielded the greatest algal population found during the survey (8,383 cells per ml.), as well as the deepest light transmission zone with 1 percent of the incident light penetrating to a depth of 65 inches.

Results of an electrofishing survey of 1-hour duration each on the Oostanaula River, the Coosa River 2 miles downstream from Rome, Ga., and the Coosa River near the State line were comparable with a similar number of game fish being observed at each station. Thus, no effects from silt on the catchable fish population were demonstrated by this investigation.

Observations indicated that heavier silts and sands continually rolled downstream in the Etowah River, temporarily settling above riffle areas and becoming resuspended immediately below them as the current pushed the particles over the riffles. This phenomenon produced a muddy water appearance below shallow obstructions in the main channel. Any type of current deflector in the center of the stream bed caused immediate settling of silt on the downstream side of the obstruction.

A thin layer of fine silt gradually settled into the bottom sand in the channel during times of low stream flow. At times of substantially increased flow, the silt is rolled up and resuspended from the sandy bottom by the force of the current, forming clouds of red water.

In regions of reduced stream velocity along the stream banks, and downstream from an inside meander, the silt settled and deposited on bottom substrates. A reduction in stream velocity also occurred in the upstream end of Lake Weiss with the resultant buildup of silt on the bottom of the flowage in the region of the old channel.

Results of core sampling of sediments deposited on the stream bed indicated a red silt layer 7-inches thick in the upper Etowah River reaches and about 10-inches thick in the upstream backwaters of Lake Weiss. Barium, which occurred in the mineral ores but not in soil erosion sediments, was used to trace the deposition of mineral washing waste solids in the Etowah and Coosa Rivers. Barium was found in Etowah and Coosa River core sediments in concentrations ranging from 1.6 to 7.0 mg./g. dry weight and in the mineral washing sludge ponds in a concentration of 10.8 mg./g. It was not found in sediments taken from tributary streams.

Potomac River

The physical effects of inert inorganic solids in the Potomac River in 1952 have been described by Ingram and Towne (1960). Glass sand wastes were discharged to a stream that joined the Potomac River approximately one-half mile downstream. Upstream form this junction, the sparklingy clear Potomac was bedded with rocks, rocky ledges, coarse gravels, and some naturally occurring clean sand. Beds of *Elodea* sp. and *Potamogeton* spp. were plentiful. Gill-breathing snails and mayflies predominated in the invertebrate population, and were found everywhere on the bottom substrates. Large unionid, pearl-button clams were common marginally. Small fish were observed in abundance. Thirteen genera of bottom animals were represented in collections from this station (figure 36).

At a station 600 yards downstream, and on the same side as the confluence of the small creek receiving glass sand wastes with the Potomac River, the stream bed was devoid of visible animal life. Blue-green algae grew marginally on the wave-washed streambank areas. On the opposite side of the stream, 13 genera of animals were found in bottom samples, making the variation, displayed between the two sides of the stream, a dramatic presentation. From the affected bank to mid-stream, rocky ledges and bottom substrata of the original Potomac River were covered by a blanket of wasted glass sand fines up to 2-feet deep. It was reported that the effects of such deposits in 1958 were observed to suppress bottom organism abundance as far as 10 miles downstream. The displayed portion of the 1952 data (Figure 36) indicates the potential for stream recovery within a shorter distance.

Bear River and Tributaries

A study was made on the Bear River and tributaries, Idaho and Utah, in August and November 1962, to obtain information leading to the development of a pollution abatement plan and to indicate levels of pollution during the irrigation and bean canning season in August and the sugar beet processing and sauerkraut canning season in November.* A

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* Survey of Interstate Pollution of the Bear River and Tributaries, Idaho-Utah, 1962. U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Water Supply and Pollution Control, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio, April 1963.

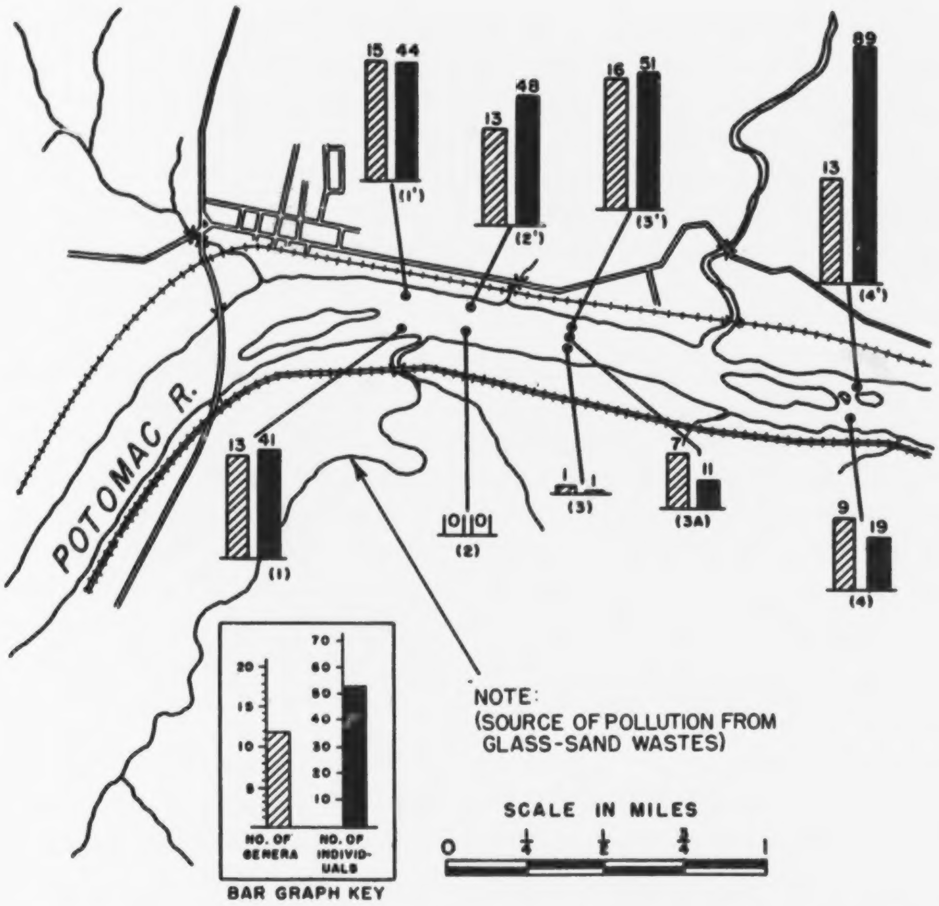
15
44
(1')
13
48
(2')
16
51
(3')
13
89
(4')
POTOMAC R.
13
41
(1)
0
0
(2)
1
1
(3)
7
11
(3A)
9
19
(4)
NOTE:
(SOURCE OF POLLUTION FROM GLASS-SAND WASTES)
SCALE IN MILES
0
1/4
1/2
3/4
1
70
60
50
40
30
20
10
20
15
10
5
NO. OF GENERA
NO. OF INDIVIDUALS
BAR GRAPH KEY

Figure 36. Genera and population numbers of bottom animals per square foot in Potomac River, September, 1952.

portion of the Bear River drains the Cache Valley lowlands where water is used to irrigate agriculture. The valley was interlaced with canals that transported water from reservoirs and stream diversion points to agricultural lands where is was applied. Ditches drained excess water from these areas and discharged it to natural drainage courses (figure 37).

Average monthly flows of 400 to 500 c.f.s. were the rule in the Bear River. During spring months, flows in excess of 1,000 c.f.s. may be expected, and in fall flows may fall short of the 400 c.f.s.

Ten stations were sampled in the Bear River from mile 99.5 to mile 51.8 (figure 38). In the two uppermost sampling stations, the stream bed was a long series of riffles interspersed with deep clear pools that offered excellent trout fishing. Here many different kinds of stream bed animals were found that formed a population of 400 per square foot.

At station 89.5, just downstream from Five Mile Creek (figure 37), sensitive caddisfly larvae and mayfly naiads were reduced and all of the remaining mayflies belonged to the genus *Tricorythodes,* which can withstand large amounts of silt. From this point downstream to Cutler Reservoir, the stream bed was silt-laden.

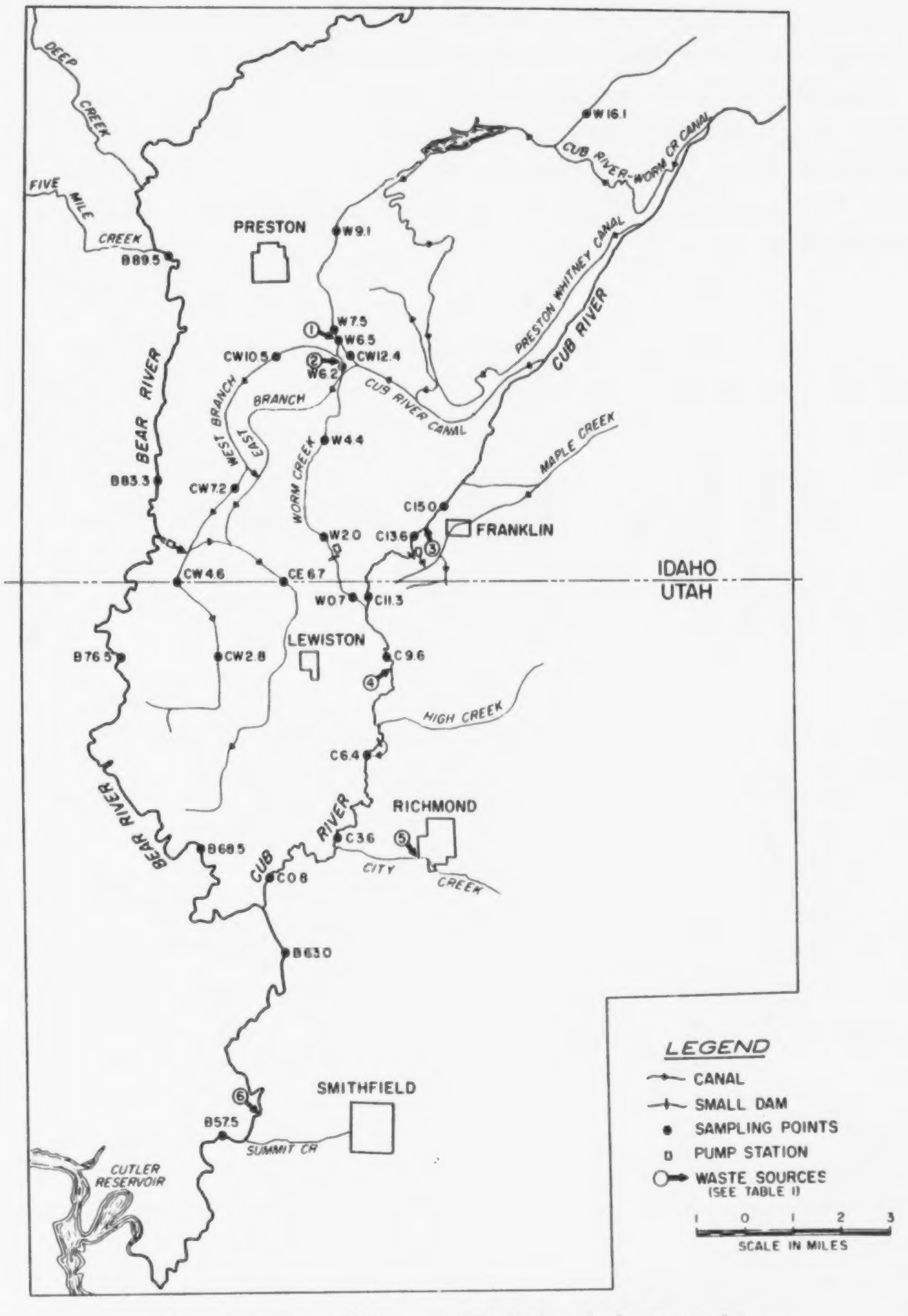
DEEP CREEK
FIVE MILE CREEK
B89.5
PRESTON
W9.1
W16.1
CUB RIVER-WORM CR CANAL
PRESTON WHITNEY CANAL
CUB RIVER
①
W7.5
W6.5
CW12.4
②
W6.2
CW10.5
WEST BRANCH
EAST BRANCH
CUB RIVER CANAL
BEAR RIVER
W4.4
MAPLE CREEK
WORM CREEK
B83.3
CW7.2
C15.0
C13.6
③
FRANKLIN
W2.0
IDAHO
UTAH
CW4.6
CE6.7
W0.7
C11.3
LEWISTON
B76.5
CW2.8
C9.6
④
HIGH CREEK
C6.4
RICHMOND
CUB RIVER
C3.6
⑤
CITY CREEK
BEAR RIVER
B68.5
C0.8
B63.0
SMITHFIELD
⑥
B57.5
SUMMIT CR
CUTLER RESERVOIR
LEGEND
CANAL
SMALL DAM
SAMPLING POINTS
PUMP STATION
WASTE SOURCES (SEE TABLE I)
1 0 1 2 3
SCALE IN MILES

Figure 37. Bear River and tributaries drainage system.

Downstream only qualitative samples of bottom organisms, taken largely from rocks used in riprapping bridge approaches, could be obtained in August because of the sandy stream bed devoid of organisms. During the fall survey, artificial masonite substrates were used with a 3-week set. These were most successful in capturing a wide variety of organisms with populations as high as 250 organisms per square foot including many intolerant mayfly naiads and caddisfly larvae.

Downstream from the entrance of organic pollution from the Cub River, there were no mayflies on the substrates in the fall and there was an increase in tolerant bloodworms. Also there was a growth of *Sphaerotilus* that practically covered the artificial substrate within the 3-week period of its set.

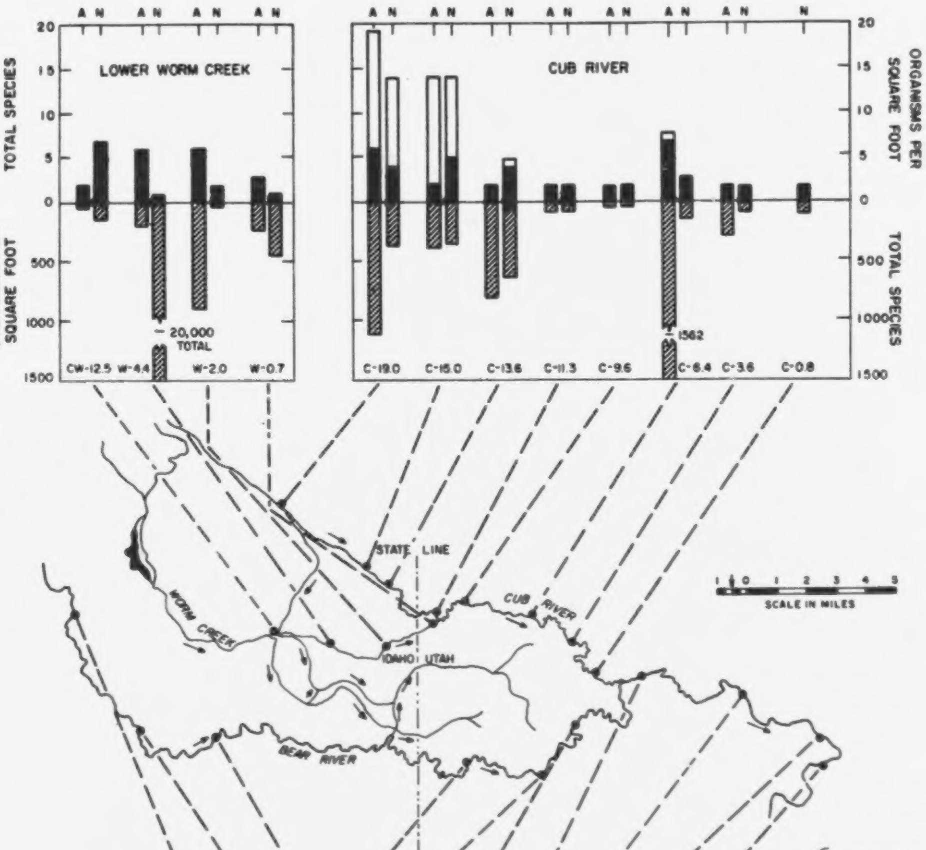

Figure 38. Benthos data, Bear River, 1962.

Stomach analyses of fish captured in this area showed that fish were feeding on the same types of organisms that were captured on the artificial substrates. Some of the individual stomachs contained as many as 15 caddisfly larvae and mayfly naiads. It seemed probable that the source of this fish food, and the source of the animals on the artificial substrates, was the highly productive riffle areas 30 or more miles upstream. Drifting mayflies have been reported as abundant as 170×10^6 *Baetis* sp. nymphs per day in large rivers (Pearson and Franklin, 1968).

It has been reported* that in the years 1910 to 1950, "The Bear River has deposited about 10 million tons of sandy sediment in its channel." This sand, 0.1 to 1 mm. in diameter, has been evenly deposited 5 to 6 feet deep over the natural gravel, clay, and silt bottom from Preston, Idaho, to Cutler Reservoir. It has come from gullies, drained by Five Mile Creek and Deep Creek, developed as a result of improper agricultural practices and poor land management. The deposited sand is of an entirely different character and origin than that of the original river channel; it not only covers the original stream bed, but also covers all but a few rocks along the river bank, thus further reducing available living spaces for organisms. Collected data on the Bear River indicate that stream bed animals were reduced from 400 per square foot in upstream natural areas to those few that were found on rocks near bridge abutments in the approximately 40 stream miles affected by sand intrusion.

Figure 38 is made somewhat unattractive as a form of data display chiefly because of the effort to show the location that each piece of data represented on a complicated stream flow system. The same graphs could have been used without drawing in the stream or using the connecting dashed lines, but, there is some advantage for data interpretation when stream locations can be viewed to gain mental perspective. The Bear River system does not lend itself well to this type of presentation because of its interlacing streams. Also, some may object to showing the number of organisms per square foot as projections below the dividing (0) line because their first impression, incorrectly, is that this represents a negative number.

Although there may be too much data displayed on one page, Figure 38 does permit the examination of the effects of more than one type of waste on stream biota. In addition to the silt pollution investigated in the Bear River, lower Worm Creek was polluted by sugar beet processing wastes. In August the stream was almost dry and the restricted flow was insufficient to permit stream recovery from the preceding fall. During fall, beet tops and pulp sludge exceeded 3 feet in depth in some stream reaches. Sludgeworms exceeded 20,000 per square foot. Only pollution tolerant organisms were found.

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* Einstein, A. J. 1951. Preliminary Report on the Sedimentation in the Bear River Channel between Cutler Dam and the Preston Bridge, Utah, to the Utah Power and Light Company, Salt Lake City (Typed Copy).

The Cub River offered excellent trout habitat in its upper reaches. Its rock and coarse gravel stream bed here provided a habitat for many stonefly naiads, mayfly naiads, caddisfly larvae, and aquatic beetle larvae, as well as a hatchery for trout eggs and developing young trout. Just upstream from Station C–13.6 (figure 38), effluent from an industrial operation that canned peas, green beans, and sauerkraut entered the stream, and the Cub River became seriously degraded. For the following 14 downstream miles, the stream bed animal population was composed principlly of a few kinds of pollution tolerant sludgeworms, bloodworms, and leeches and occasionally large populations of these formed when water quality would permit.

7

TOXIC MATERIALS

Chattooga River

STUDIES on the Chattooga River* with a mean daily discharge of 94 c.f.s. began upstream from Trion, Ga., across the Georgia-Alabama State line and into Lake Weiss (Figure 32). Textile wastes and organic wastes entered the stream at Trion, Ga. and organic wastes, principally, entered at Summerville, Ga.

Water samples were collected daily for 14 days for dissolved oxygen determinations. Downstream from Trion, Ga., industrial and domestic wastes drastically reduced, and at times eliminated, the dissolved oxygen resources of the river (figure 39). This display of data is dramatic because a particular level or concentration of a water quality constituent could be chosen as an acceptable minimal criterion and the percentage of time that the criterion was not met was accentuated.

Discharged industrial wastes to the Chattooga River contained dyes in abundance. When river waters are polluted by dyes or similar wastes containing a variety of unnatural hues and colors, visual observations can often be more informative and provide a more realistic picture of stream appearance than routine comparison with laboratory color intensity standards. The color of the river downstream from Trion changed from day to day according to the type, volume, and intensity of dye stuffs included in the textile mill wastes. Changing from deep blue to black to brillant green, it faded to less intense shades of gray and green downstream.

During August 1962, 20 different kinds of stream bed animals, predominantly insects sensitive towards pollution were found in the rocks and coarse gravels upstream from Trion, Ga. Three miles downstream from Trion, no stream bed animals were found (figure 40). Only a layer of black sludge covered the stream bed. Industrial wastes were clearly toxic; and, they were present in sufficient concentration to eliminate the bottom animal community.

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* Report on Coosa River System, Georgia-Alabama. Op. cit.

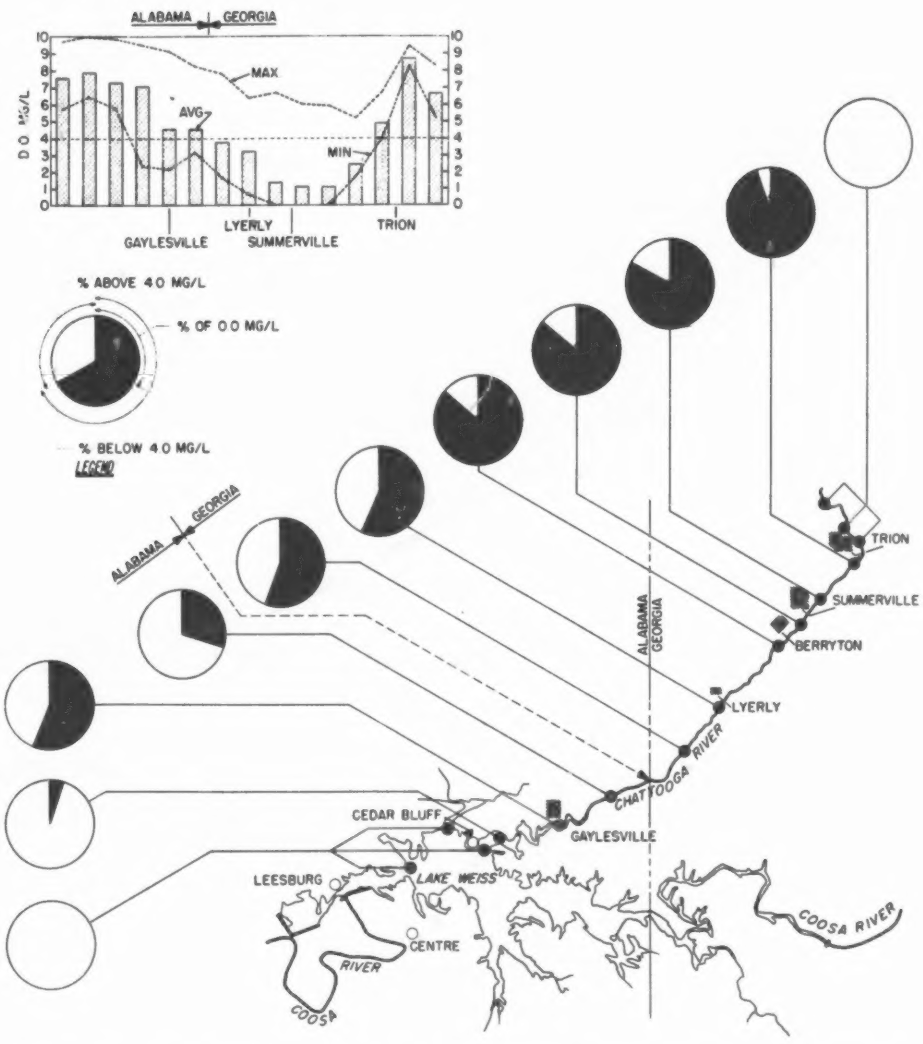

ALABAMA
GEORGIA
D.O. MG/L
0
1
2
3
4
5
6
7
8
9
10
MAX
AVG
MIN
GAYLESVILLE
LYERLY
SUMMERVILLE
TRION
% ABOVE 4.0 MG/L
% OF 0.0 MG/L
% BELOW 4.0 MG/L
LEGEND
ALABAMA
GEORGIA
TRION
SUMMERVILLE
BERRYTON
LYERLY
CHATTOOGA RIVER
GAYLESVILLE
CEDAR BLUFF
LEESBURG
LAKE WEISS
CENTRE
COOSA RIVER
RIVER
COOSA

Figure 39. Dissolved oxygen in the Chattooga River showing the percentage D.O. below 4 mg/1, August 1962

Six miles downstream from Trion, stream bed conditions were only slightly improved. The settled sludge was less than 1-inch thick. Tolerant and very tolerant animals were predominant. A tolerant green alga, *Stigeoclonium* sp., adhered to bottom deposits.

Two miles farther downstream the green alga was still evident; filamentous blue-green algae and diatoms were able to tolerate the environment here and were attached to rocks. Sludgeworms, the only benthic organism encountered, survived the diluted toxic materials and responded to the food in the organic pollution producing a population of 680 per square foot.

After receiving toxic and organic wastes at Trion, Ga. the stream did not support a stream bed animal population indicative of unpolluted waters for a distance of about 22 stream miles. In the affected stream reach,

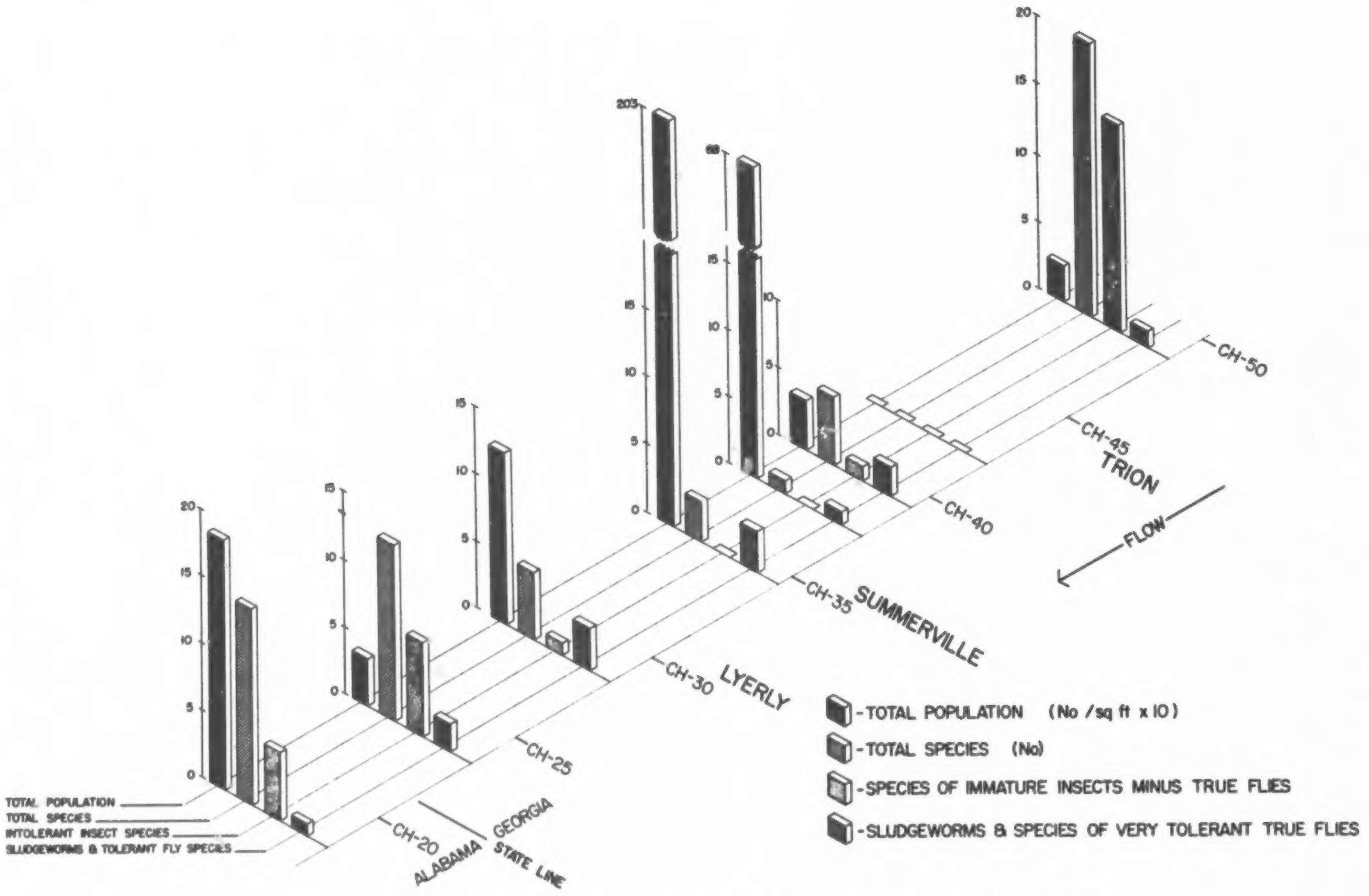


Figure 40. Stream bed animal population in Chattooga River, Ga. August 1962

sensitive insect larvae were drastically reduced or eliminated, and pollution tolerant sludgeworms and associates responded to organic wastes with dense populations where the concentration of toxic materials did not preclude or hamper their existence or development.

Population trends are more easily visualized in figure 40 than in previously discussed three dimensional presentations because the amount of data displayed in one area is less. By means of this device it is possible to form a mental concept among displayed data grouped for a particular station, as well as any single data component among several stations.

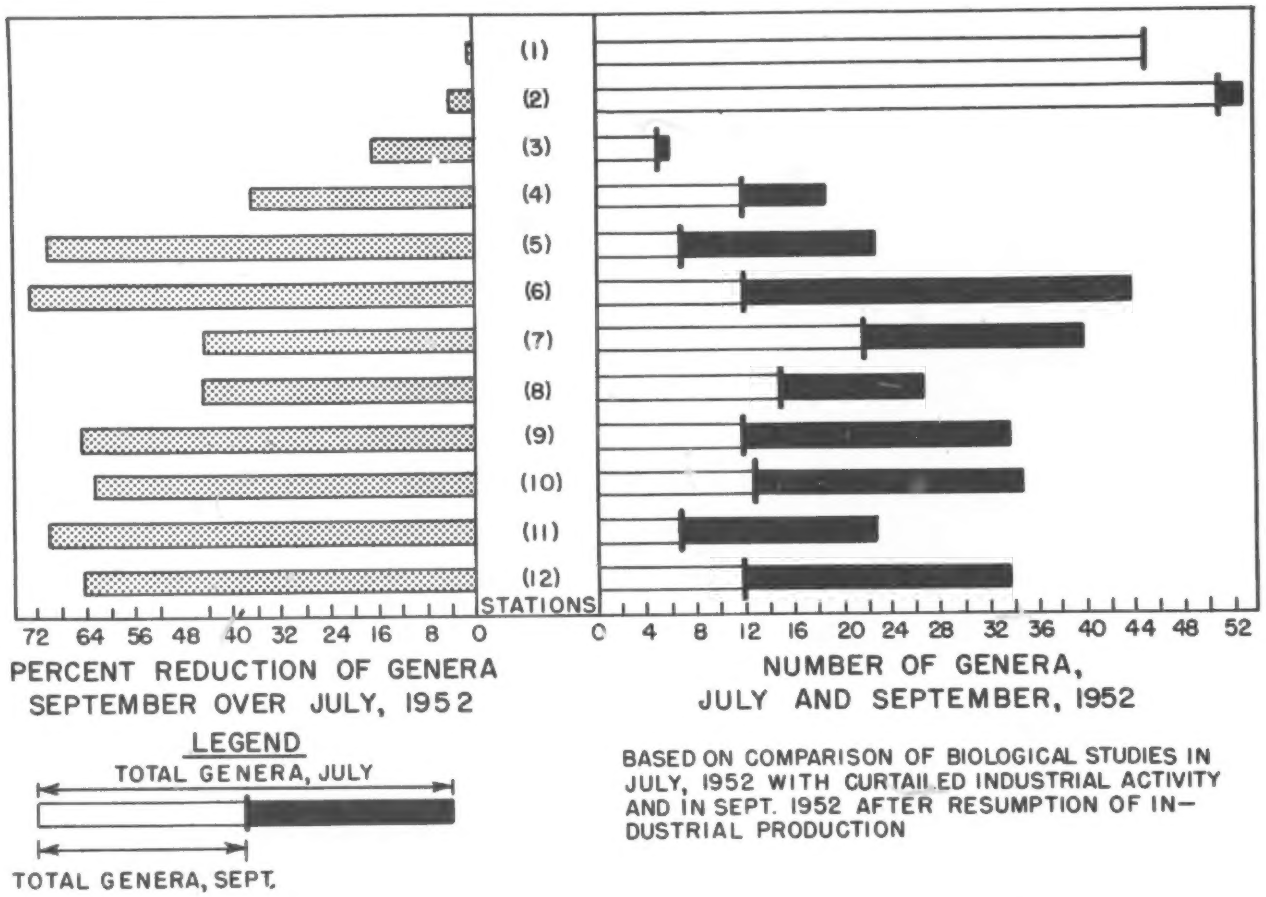
Field investigations such as has been described above depict severely toxic conditions. Toxic wastes may eliminate fish populations in certain areas or they may decimate only certain species or certain developmental stages. Adult fish may migrate into an area and live where reproduction is not successful. Some fishfood organisms are more sensitive to certain toxic materials than are fish, and fish populations may be reduced because of a lack of food rather than a direct killing of fish.

Toxic wastes may interfere with the natural purification process in water by interfering with the life processes of those organisms that break down the wastes. The character of the water and its mineral content can alter considerably the toxic effects of a given chemical or waste. The combination of two or more metals may make them several times more toxic to aquatic life than when they occur separately in the environment.

The bioassay is a very important biological tool to use in conjunction with field investigation when toxicities are suspected. The bioassay, conducted under controlled experimental conditions, may be short term (96 hours or less) to determine acute toxicity or long term (days, weeks or months) to determine effects of chronic exposure to test organisms of suspected toxicants, and physiological changes produced within test organisms when exposed to sublethal concentrations of a material that is toxic in higher concentrations. The bioassay may be conducted in a static water environment such as an aquarium, jar, or tank, in a complex flow-through laboratory test chamber, or in situ within the stream or lake. Details for conducting bioassays are presented in the current edition of "Standard Methods for the Examination of Water and Wastewaters."

Mahoning River

In 1952, a steel strike curtailed industrial production along the Mahoning River, Ohio, (Ingram and Bartsch, 1960). July collections were made in that year while the load of remaining pollution came from untreated municipal sewage (Figure 41). September collections were made at the same stations after industrial production was resumed, and the pollutional load consisted of both industrial and municipal wastes. Differences in the number of genera of plants and animals under conditions existing in July and September are shown in the right-hand part of figure 41. Stations 1



BASED ON COMPARISON OF BIOLOGICAL STUDIES IN JULY, 1952 WITH CURTAILED INDUSTRIAL ACTIVITY AND IN SEPT. 1952 AFTER RESUMPTION OF INDUSTRIAL PRODUCTION

Figure 41. Effects of industrial wastes on genera of organisms in Mahoning River, 1952.

and 2 were control reaches; all other stations were subjected to varying loads of pollution. The left-hand side shows the percentage reduction of genera in September over July, 1952. It is obvious at a glance that the biotic variety of the river was reduced concurrently with resumption of industrial activity and the resulting increased toxic pollutional loads reaching the stream. That the indicated reduction is not attributable to seasonal variation of aquatic life is attested to by the similarities in generic numbers collected at upstream Control Stations 1 and 2 in both July and September.

The Mahoning River drains an area of 1,131 square miles; it begins near Alliance, Ohio, flows northeasterly to Warren, Ohio, southeasterly through Youngstown, Ohio, and joins the Shenango River near New Castle, Pa., to form the Beaver River. One of the most highly industrialized areas in the United States is drained by the Mahoning where 10 percent of this country's steel production is concentrated in its basin.

Maximum river temperatures at Lowellville, Ohio, exceeded 93° F. during 7 months in 1964 in May through November, and exceeded 100° F. in June, July, and September; phenol concentrations were as high as 0.28 mg/l here in January 1965; cyanide values averaged 0.25 mg/1 from November, 1952, through September, 1953; ammonia (as NH_3) averaged 3.3 mg/l annually.* Reclaiming operations in the Mahoning River at Youngstown were employed in a 4½-mile reach to separate and remove iron deposits from river bottom sludge.

In a study during the week of January 4, 1965, bottom organisms were reduced in numbers from over 1,300 per square foot upstream from Newton Falls, Ohio, to about 350 per square foot upstream and downstream from Warren, 300 per square foot at Lowellville (Mile 11), and 850 per square foot at the first bridge crossing downstream from the Ohio-Pennsylvania State line (figure 42). Similarly, 11 different kinds of organisms were found upstream from Newton Falls, only one kind, a pollution-tolerant organism, was found at Lowellville (Mile 11), and 3 kinds were found at the first bridge crossing downstream from the State line (figure 43). Although few in numbers downstream from Newton Falls, clean-water associated organisms were found to the highway 422 bridge upstream from Warren, Ohio. Clean-water-associated organisms were not found throughout the remainder of the Mahoning River. Only pollution-tolerant sludgeworms persisted at Lowellville, and only pollution-tolerant sludgeworms and leeches and one kind of tolerant snail were found at the station downstream from the State line. The absence of clean-water-associated fish food organisms in the Mahoning River downstream from Warren, Ohio, the severe decrease in the diversity of bottom organisms, and the generally low numbers of stream bed animals at most sampling stations, attests to the severely polluted condition of the river and its toxicity from Warren, Ohio, to its confluence with the Shenango River in Pennsylvania.

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* Report on Quality of Interstate Waters of Mahoning River, Ohio-Pennsylvania. U.S. Department of Health, Education, and Welfare, Public Health Service, Region V, Chicago, Ill., Jan. 1965.

The bottom of the Mahoning River throughout the reach studied was generally rock and rubble with sludge along the shores and in many slack water areas. Such a rubble substrate would be expected to support a bountiful fish food organism population when not polluted. In many areas, oil formed a film on the water's surface, adhering to twigs, shoreline grasses and debris, and became mixed with the sludges. Substrate

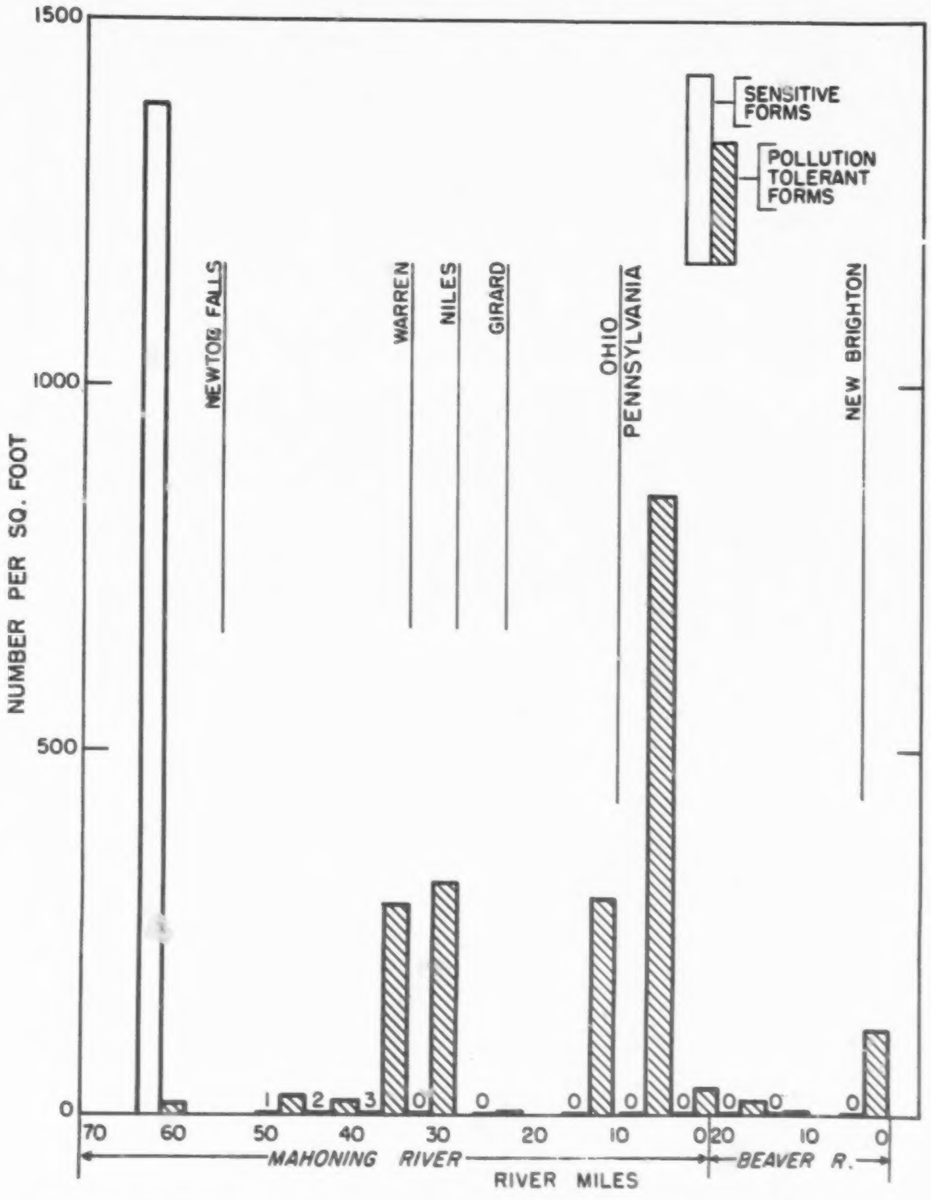

Figure 42. Numbers of stream bed animals, Mahoning-Beaver Rivers, January 1965.

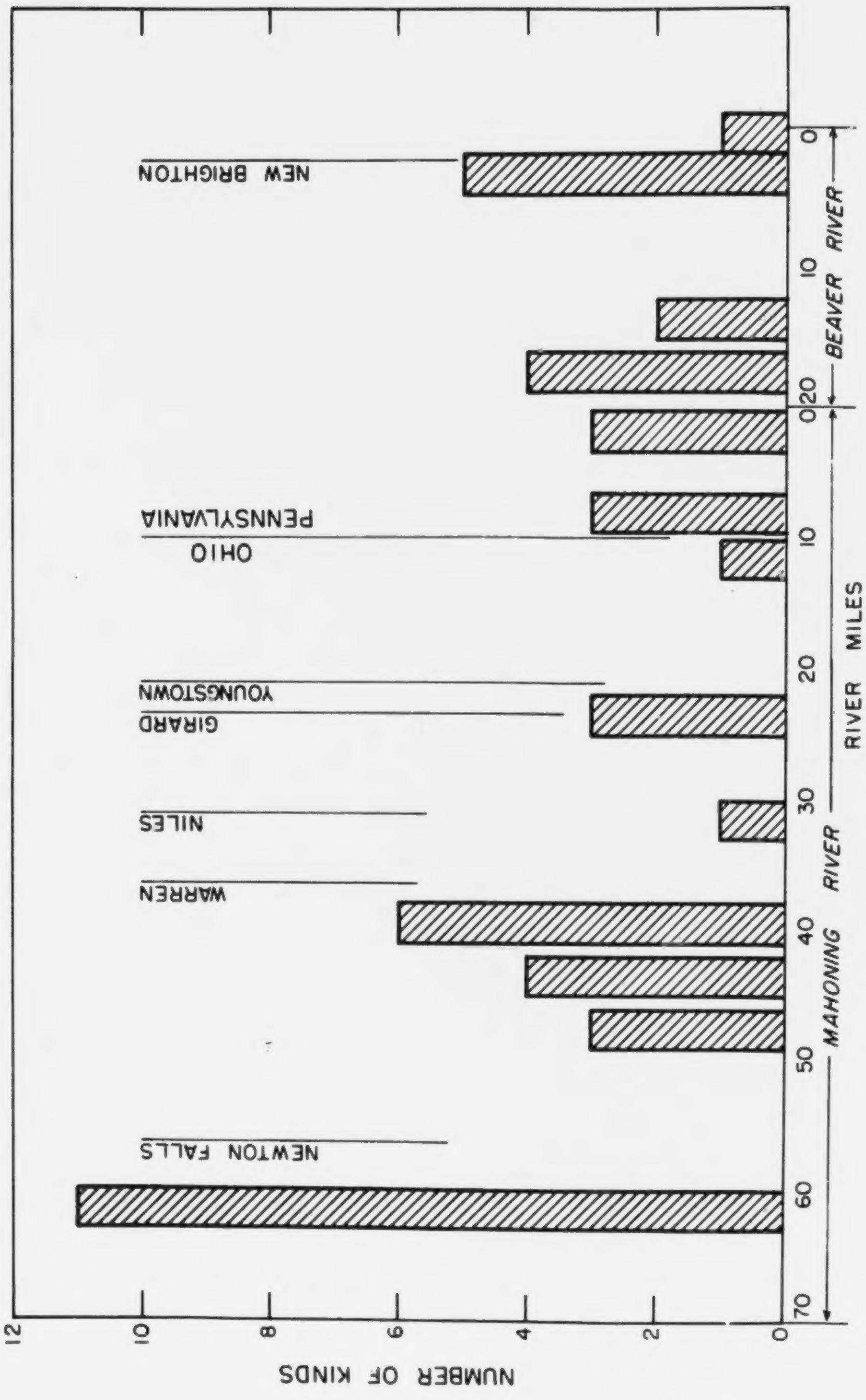

Figure 43. Kinds of stream bed animals, Mahoning-Beaver Rivers, January 1965.

rocks and rubble were covered with a thick iron deposit that was harmful to bottom organisms in the Lowellville-State line reach.

Conditions of existence were only slightly improved in the Beaver

River. Sludgeworm populations were reduced from those found in the more polluted reaches of the Mahoning River, which indicates a reduction in the organic food supply. At New Brighton, Pa., partial stream recovery was found. The different kinds of organisms had increased and stoneflies were observed in small numbers on rocks in the shallow water near the shore. These were not found in quantitative samples taken from deeper water where the impact of pollution would be expected to be greatest.

Oil was also found throughout the Beaver River. Many of the bottom rock were red in color and showed evidence of an iron precipitate. Colonizing the rock's surface in shallower waters was a growth of slick, slimy algae often characteristic of polluted water.

Fisheries investigators have reported that the Mahoning River does not support a catchable fish population downstream from Warren, Ohio, to its confluence with the Shenango River, and that the Beaver River supports a catchable fish population only in its lower reach in the New Brighton area. This was substantiated by an examination of the bottom organism population. In those areas where fishing was not reported, there were no bottom organisms on which fish normally feed.

Results of an examination of the phytoplankton population were similar to those found for the bottom organism population. Values of total counts upstream from Newton Falls, Ohio, were in a range that would be expected in an unpolluted stream during the winter months (figure 44). Downstream from the U.S. Highway 5 bridge (mile 47.4) total count values were substantially reduced and remained so throughout the remainder of the Mahoning River. At Lowellville, Ohio, and at the first bridge crossing downstream from the Ohio-Pennsylvania State line, total count values were one-fourth of those upstream from Newton Falls. Some recovery was found at the highway 18 bridge upstream from the confluence of the Mahoning River with the Shenango River. Depressed algal counts demonstrate the degrading effects of pollution on this primary food source for aquatic life in the stream. The low phytoplankton total count values and the low population numbers found in the bottom organism population is strongly suggestive of the action of a toxic substance or substances to aquatic life.

Ten Mile River

Ten Mile River begins at the outlet of a pond in the northwest part of Plainville, Mass. It follows an irregular course for 21 miles before it joins the Seekonk River in East Providence, R.I. At one time it was stocked with brook trout at Attleboro, Mass., some 8.3 miles downstream from its mouth. During the 1964 survey, it received municipal, plating, pickling, chemical, and textile wastes, and was considered too polluted to be

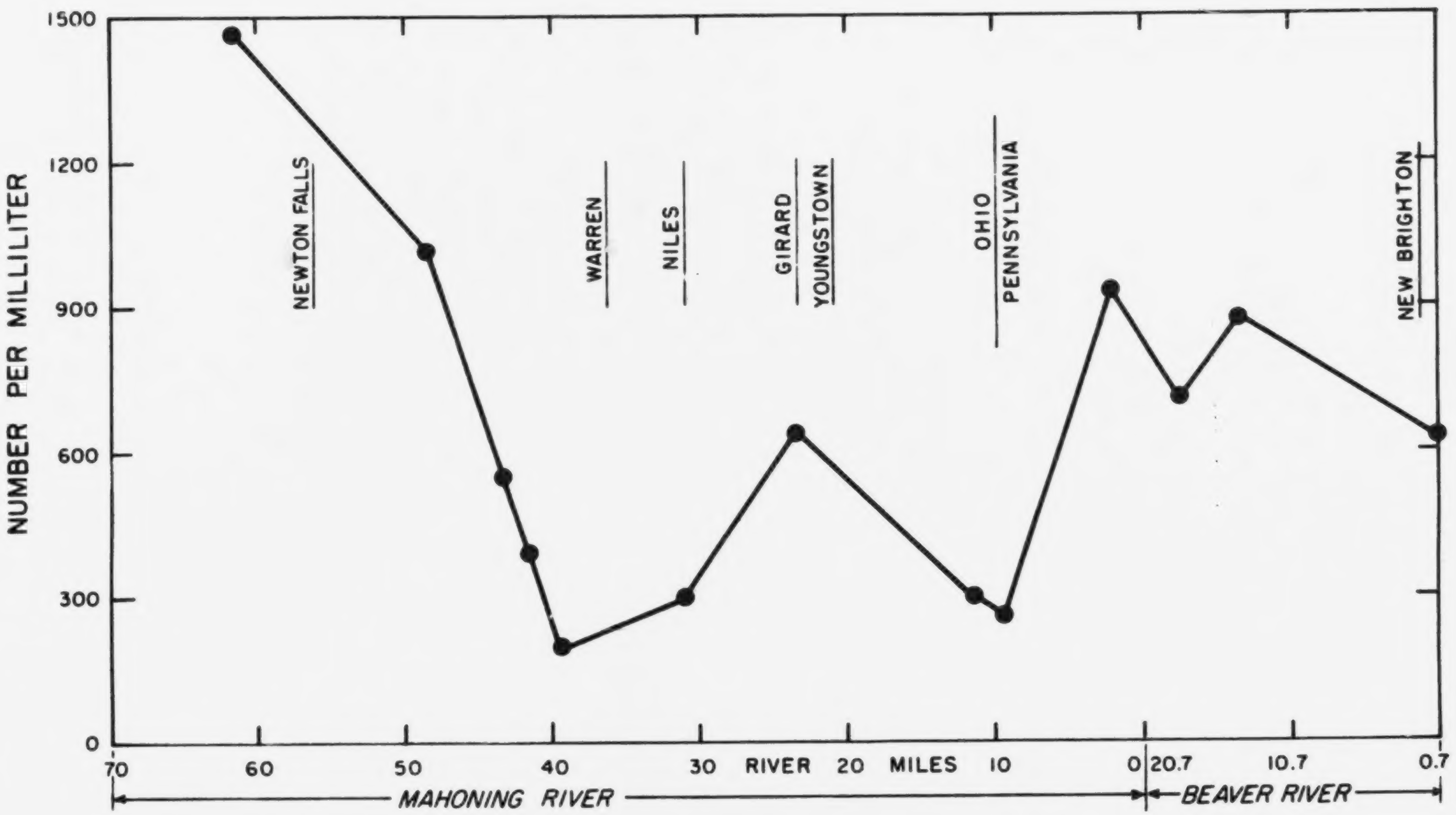

Figure 44. Phytoplankton in Mahoning-Beaver Rivers, January 1965

stocked with any fish downstream from its headwaters.* Thirty-five small metal plating plants are situated in Plainville, North Attleboro, and Attleboro, Mass.

Ten Mile River was severely degraded downstream from North Attleboro, Mass., to the point where it joins the Seekonk River in East Providence, R.I. In this 19 mile reach, Ten Mile River supported a minimal population of clean-water-associated organisms only upstream from North Attleboro.

Extensive sludge deposits, slimes, stalked protozoa, and pollution-tolerant populations of sludgeworms and midges approaching 22,000 organisms per square foot of stream bottom were found in the reach between the North Attleboro sewage treatment plant and Farmers Pond near Attleboro, Mass. (figure 45). Pollution-tolerant sludgeworms and midges were less abundant downstream in Attleboro. Few different kinds of organisms and the presence of extensive sludge deposits impregnated with grease indicated severe pollution and toxicity in this reach of Ten Mile River.

Only 4 kinds of bottom organisms were present in Ten Mile River upstream from the Attleboro sewage treatment plant and the confluence with

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* Report on Pollution of Interstate Waters of the Blackstone and Ten Mile Rivers. Op. cit.

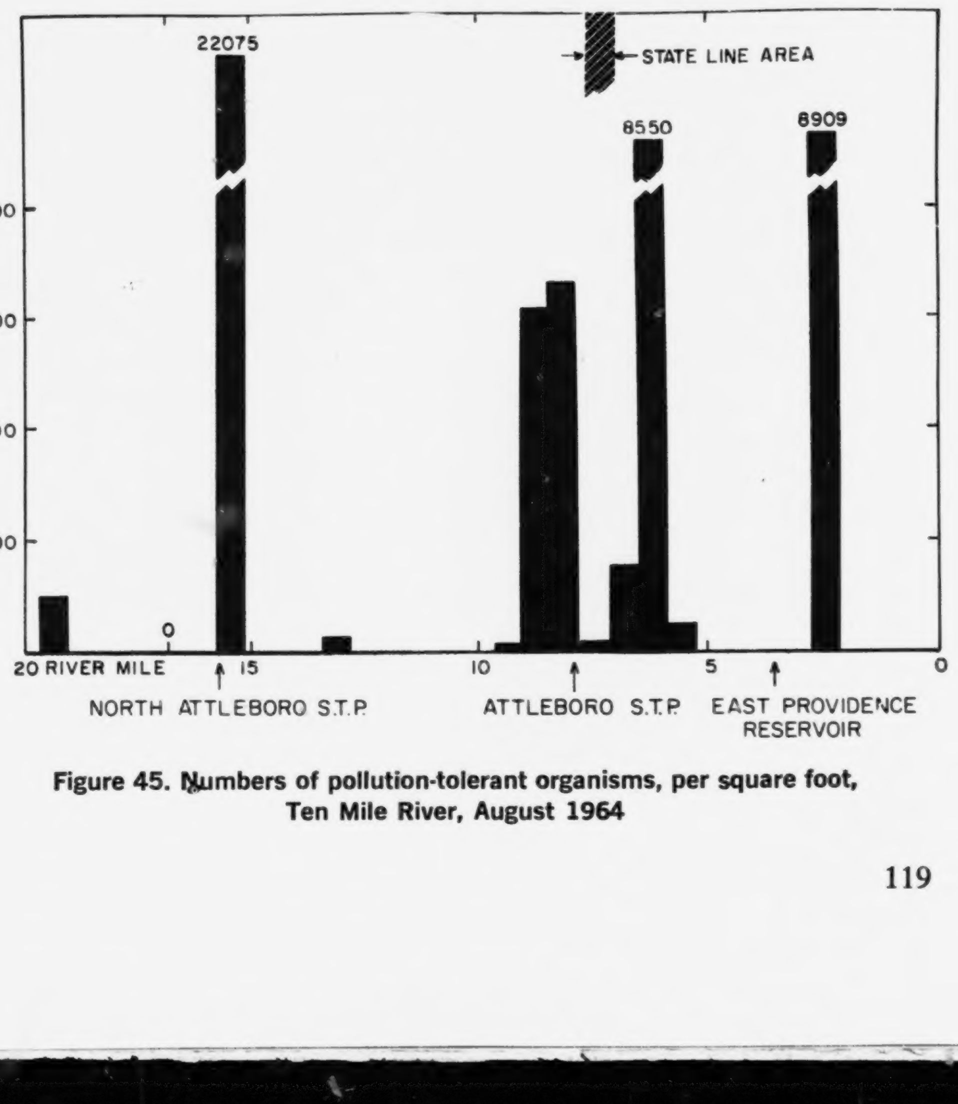

Figure 45. Numbers of pollution-tolerant organisms, per square foot, Ten Mile River, August 1964

an unnamed tributary. Pollution-tolerant midges and sludgeworms were well represented, and stream bottom materials were covered with an oily sludge and slimes. Downstream from this tributary the number of individuals representing the four kinds of bottom organisms was much reduced. Although four kinds of organisms were still present, the decrease in numbers of individuals suggests that wastes entering from the tributary were toxic. No organisms were found in the oily sludge-covered bottom of this purple-black tributary downstream from one of the dyeing and finishing plants.

Effluents from the Attleboro sewage treatment plant contributed to extensive deposition of sludge and, because of unsuitable water quality, a reduction in both numbers and kinds of bottom organisms occurred (Figure 45). Even sludgeworms found conditions of existence restrictive. Slimes, algae, and sludges covered much of the gravel and sandy stream bottom. For the remainder of its length, Ten Mile River exhibited varying degrees of degradation, usually severe.

8

ACID MINE WASTES

A RECENT U.S. Department of the Interior report indicated that 4,800 miles of streams and 29,000 surface acres of impoundments and reservoirs are affected seriously by surface coal mining operations alone (Anon. 1967). Inventories of stream pollution magnitude and source have highlighted the seriousness of the problem. There are about 66,500 sources of coal mine drainage pollution in Appalachia in active and inactive mines. Pollutants in this mine drainage reduce about 10,500 miles of streams below desirable levels of quality* (figure 46).

The pollution of streams by coal mine drainage can be extremely damaging to aquatic life. Streams so polluted generally support only a few species of particularly tolerant plants and animals.

Damages to aquatic life from acid mine drainage are attributed usually to high concentrations of mineral acids, the ions of iron, sulfates, and the deposition of a smothering blanket of precipitated iron salts on the stream bed.** In addition, zinc, copper, and aluminum have occurred at lethal concentrations to aquatic life in acid mine drainage; arsenic and cadmium have been found at near lethal levels. The toxicities are increased by synergism among several of the elements including zinc with copper, zinc with cadmium, and copper with cadmium. Toxicities of iron, copper, and zinc solutions are much greater in acid waters polluted by coal mine drainage than in neutral or alkaline waters. Because of the complex chemical nature of coal mine drainage, it is impossible to assign its toxicity towards aquatic life to any single chemical constituent.

Toxic chemicals in acid mine drainage eliminate sensitive aquatic life; tolerant organisms flourish occasionally to great numbers apparently unaffected by the pollutants. Fish are usually not found when the pH of the

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* Stream Pollution by Coal Mine Drainage in Appalachia. U.S. Department of the Interior, Federal Water Pollution Control Administration, 1967.

** Richard W. Warner, Biologist, Technical Advisory and Investigations Branch, personal communication.

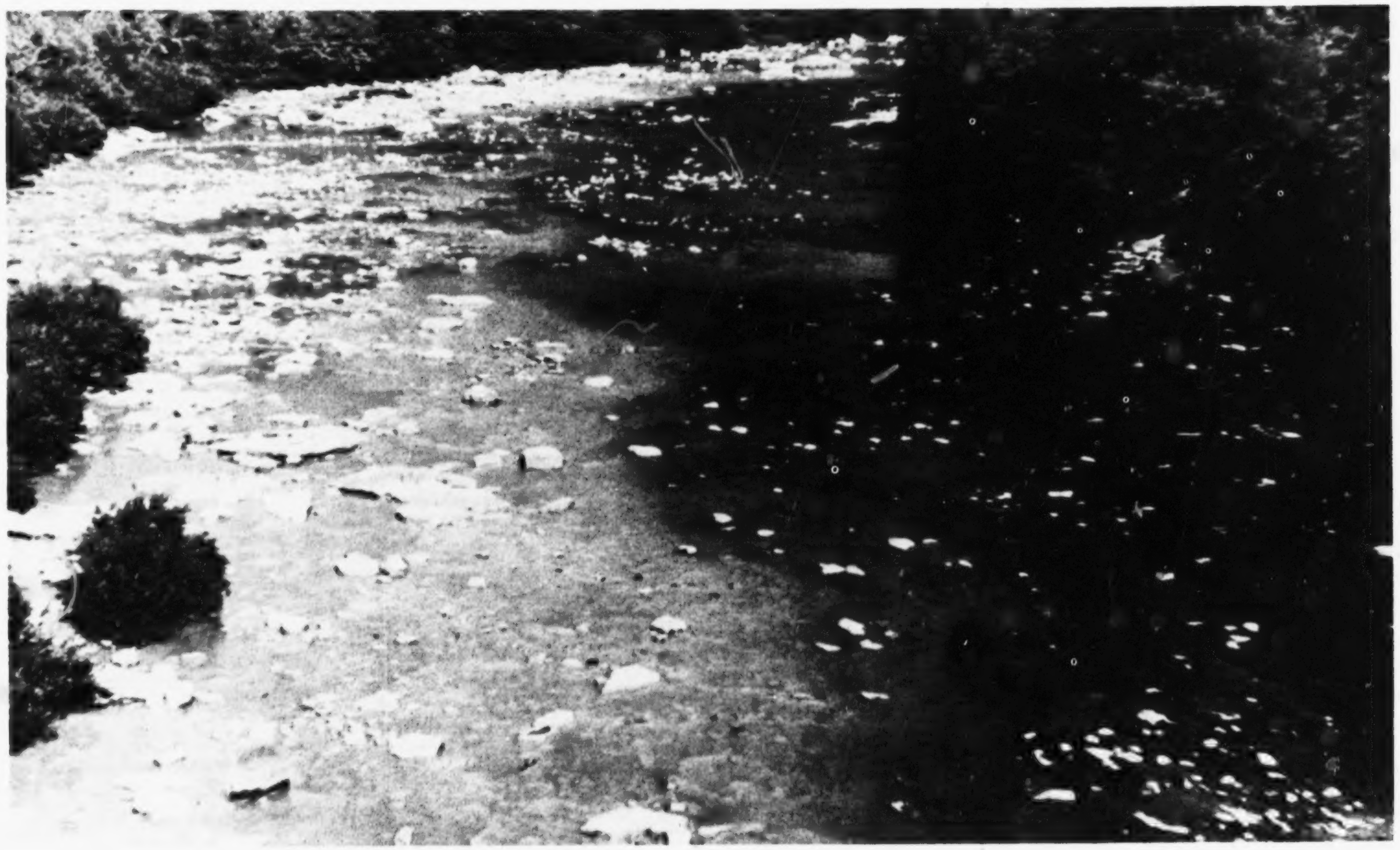

Figure 46. Acid mine discharges kill natural stream bed organisms. Note polluted stream bed on viewers left compared to relatively unpolluted stream bed on viewers right.

stream is lower than 4.5. Conversely, populations of midge larvae, *Chironomus* spp., may develop to nuisance proportions.

With a stream pH of 4.0 or lower, cattails, *Typha* spp., and some mosses will flourish; other vascular plants are not found generally. Moore and Clarkson (1967) studied the Monongahela River, W. Va., and concluded that acid mine drainage does not affect the occurrence and distribution of vascular aquatic plants. They found that nitrogen, calcium, total acidity, iron, pH, and rate of flow had no significant effect on plant distribution, but, that type of substratum was the most important factor affecting plant growth and phosphate content and water level fluctuations were significant.

With a stream pH of 4.0 or lower, dense mats of the green alga, *Ulothrix tenerrima* Kuetzing, are usually common enough to attract the attention of casual observers. Gelatinous mats of chlorophyll-containing flagellates, *Euglena* spp., often color stream beds dark green. Microscopic

Figure 47. Water quality analyses of stream samples inside a 40-foot mobile laboratory.

examination often reveals other species of green algae including *Microspora* spp., *Microthamnion* sp., the flagellate *Chlamydomonas* spp., great numbers of diatoms *Eunotia* spp., *Pinnularia* spp., and *Navicula* spp., and lesser numbers of *Surirella* spp.

In severely polluted stream reaches, especially near the mine adits from which polluted water flows, no stream bed animals will be found. In less severely polluted reaches, common inhabitants include midges (*Chironomus* spp.), alderflies (*Sialis* sp.), fishflies (*Chauloides* spp.), craneflies (*Antocha* sp.), dytiscid beetles, and caddisflies (*Ptilostomis* sp.). Conspicuous by their absence are crayfish, blackflies, mayflies, stoneflies, and most species of caddisflies.

Upstream reaches, not polluted by acid mine drainage, may support several species of rooted and floating vascular plants, 20 or 30 species of algae, 15 or 20 or more species of stream bed animals, and a mixed community of fishes. Severely polluted stream reaches may support only three or four species of algae. Less severely polluted reaches may support one or two species of vascular plants, three or four species of algae, three or four species of stream bed animals, and no fish.

Dr. Max Katz* summarized much literature on low pH effects and concluded that: pH 6.5 to 7.0 delayed spawning in some fish species but otherwise was harmless except when concentrations of heavy metals or cyanides may be made toxic to fish; pH 6.0 to 6.5 interfered with spawning and hatching of eggs of some fish species; pH 5.0 to 6.0 may be lethal to eggs and larvae of sensitive fish species and will favor dominance of some blue-green algae; pH 4.5 to 5.0 will prohibit reproduction among salmonids and is the threshold range for blackflies, mayflies, and stoneflies in numbers; pH 4.0 to 4.5 permits pike to survive but perch, bream, and roach can only become temporarily acclimated. Observations on pH ranges <4.0 were similar to those described earlier.

Acid pollution of a stream may have additional effects not generally recognized. When water is too acid, it cannot be used for household purposes, livestock watering, or industrial use, without expensive treatment. Wildlife, unwilling to drink acid water, is usually absent near badly polluted areas. Iron hydroxide deposits in stream channels and lack of desirable fish and wildlife in or near acid streams result in decreased land values (Parsons, 1952).

Lackey (1938) writes that one of the most noticeable features of streams or pools receiving drainage from coal mines, either active or abandoned, and their accompanying refuse piles, is the color, varying from almost clear to a deep copper or dark brown. In some instances the water may be clear but appear colored because the stream bed is lined with an iron oxide deposit. Lackey found *Euglena mutabilis* (figure 48) so abundant that they were responsible for a green coating on sticks, leaves, and stones. Such a coating comprised, "at a conservative estimate"

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* Dr. Max Katz, University of Washington, personal communication.

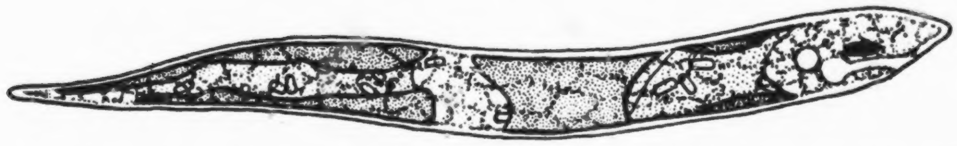

Figure 48. ***Euglena mutabillis*, showing two or three heavy chloroplastids, conspicuous stigma, small rod-like paramylum bodies, and apparent absence of flagellum. After Lackey (1939).**

over 1 million organisms per m.^{2} of surface. This one organism, Lackey found, was the most characteristic of highly acid streams. It was present in even the thinnest trickles over vertical faces of rocks in some instances, extending well back into mine openings where there was but little light. The organism is apparently devoid of a flagellum, and its migrations to favored situations must be accomplished by crawling. Lackey found that if a bottle of water containing a large number of the organisms and a half inch of mud were shaken vigorously, the mud settled within 2 or 3 minutes, and in a half hour or less there was a green covering of *Euglena* on its surface. Lackey (1939) listed the number of species of plant and animal groups that occurred below pH 4.0 (table 5).

More than a decade ago, Turner (1958) calculated the monetary damages to 16.3 miles of Goose Creek, a tributary of the South Fork of the Kentucky River, from acid pollution from an operating coal mine to be $13,325. The monetary value was arrived through electro-shocking two similar areas, one upstream from and one downstream from the pollution, and through creel-census.

Table 5. Distribution of Recognized Species of Plants and Animals Occurring at or Below pH 3.9. (After Lackey, 1939)

Plants	Number of Species	Animals	Number of Species
Thallophyta:		Protozoa:	
Fungi	2	Mastigophora:	
Algae:		Euglenidae	7
Myxophyceae	3	Protomastigina	7
Chrysophyceae:		Sarcodina:	
Chrysomonadales	3	Rhizopoda	15
Chrysotrichales	1	Heliozoa	2
Bacillarieae:		Infusoria:	
Pennales	5	Ciliata	19
Chlorophyceae:		Trochelminthes:	
Volvocales	1	Rotatoria	6
Ulotrichales	2	Gastrotricha	1
Chlorococcales	1	Nemathelminthes:	
Zynematales	6	Nematoda	1
Dinophyceae	2	Arthropoda:	
Bryophyta	1	Crustacea:	
Pteridophyta	1	Isopoda	1
Spermatophyta	1	Copepoda	1
		Arachnida:	
		Tardigrada	1
		Insecta	8
		Amphibia	1

Monongahela River System

During August and September 1963, a study was made of the Monongahela River System* Mine drainage, containing sulfuric acid and acid

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* Report on Pollution of the Interstate Waters of the Monongahela River System, A. D. Sidio and K. M. Mackenthun, U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, December 1963.

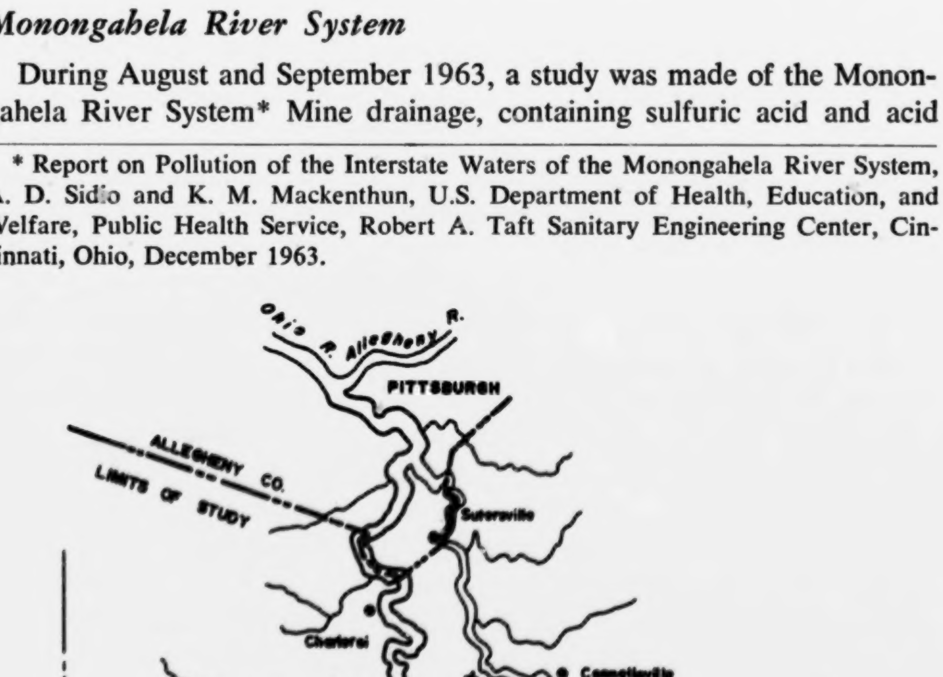
Ohio R.
Allegheny R.
PITTSBURGH
ALLEGHENY CO.
LIMITS OF STUDY
Sutersville
Charleroi
Connellsville
Youghiogheny
Casselman
River
Confluence
Greensboro
Point Marion
Dunkard Cr.
PA.
W. VA.
MD.
Lake Lynn
Cheat
River
Friendsville
Morgantown
Fairmont
Tygart
Grafton
Rowlesburg
Tygart River Reservoir
River
Oakland
Clarksburg
West Fork
Weston
Buckhannon
River
Parsons
Elkins
N
MILES
0
10
20

Figure 49. Streams within the Monongahela River Basin.

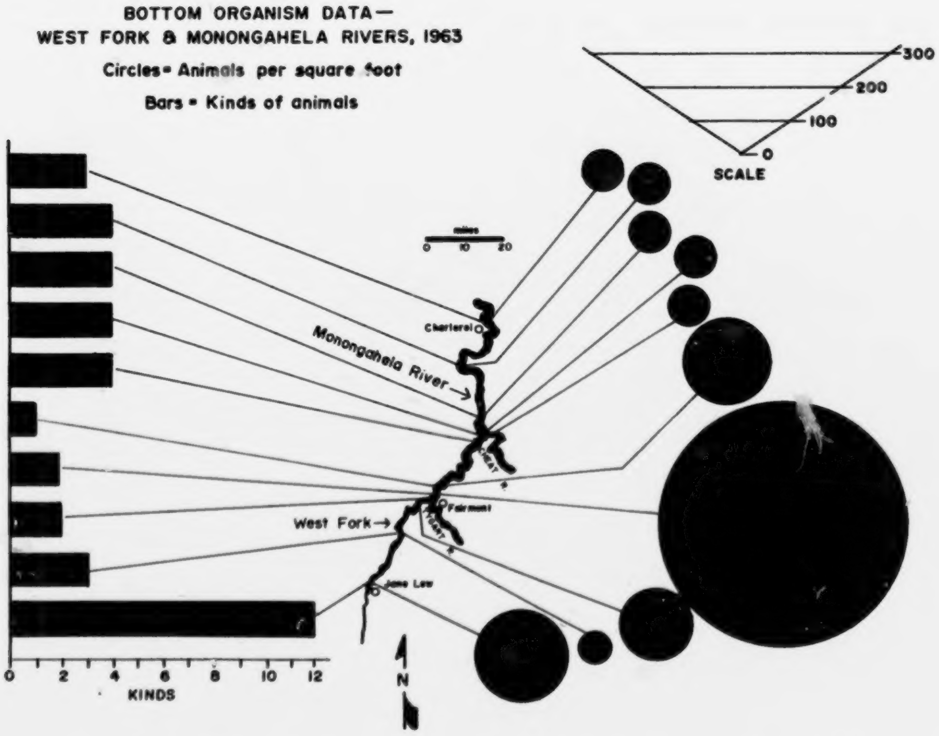

Figure 50. Stream bed organisms, Monongahela River system, 1963.

salts, was the most damaging waste entering the streams within this basin. Annual damages, because of acid conditions in the Monongahela River, were estimated at $2,250,000.

The Monongahela River is formed by the confluence of the West Fork and Tygart rivers at Fairmont, W. Va. (figure 49). The drainage basin includes the southwest corner of Pennsylvania, the northeast portion of West Virginia, and a small section of western Maryland. The basin drains an area of 7,380 square miles. The river flows in a northerly direction and joins the Allegheny River at Pittsburgh, Pa., to form the Ohio River. The main stem of the Monongahela River flows through the Appalachian Plateau region and is characterized by rugged topography, with narrow stream valleys several hundred feet below the level of the uplands.

Downstream from Jane Lew, W. Va., on the West Fork, many different kinds of bottom organisms were collected indicating a healthy stream that is suitable to support fish and other animal life (Figure 50). Aquatic mayfly and caddisfly forms were abundant here. Downstream from this station on both the West Fork and Monongahela Rivers, the stream was degraded by acid mine pollution. The combined effects of acidity and the deposition of sediments caused by mine drainage resulted in a drastic decrease in both kinds and numbers of stream bed animals. At Jane Lew there were 12 different kinds of stream bed animals in collected samples; at all downstream stations there were four or less. At downstream sta-

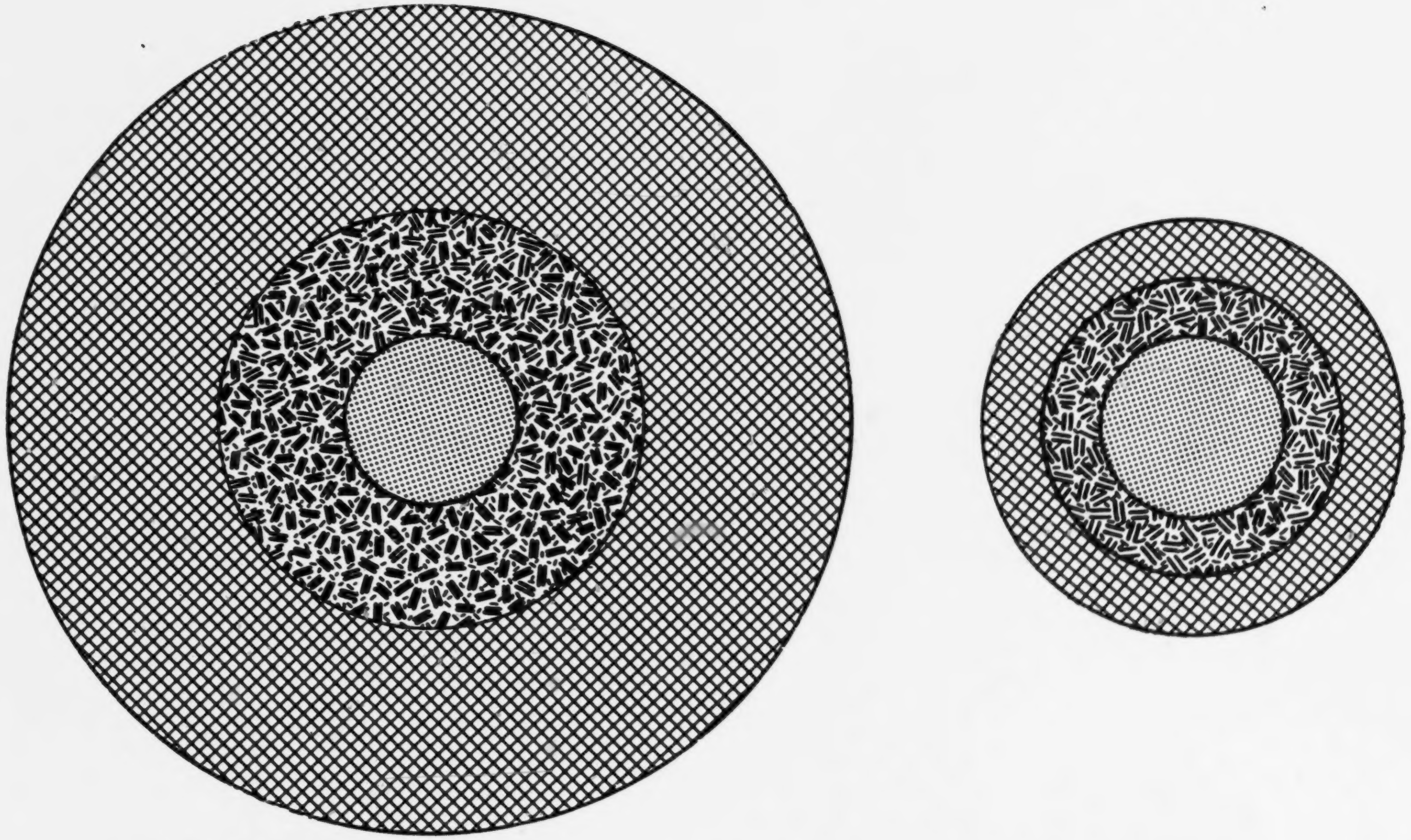

Figure 51. Relative ratios of circle diameters to circle areas. From left and center, 1 : , 2.5 : 2.5, : 5.

tions, the numbers of organisms per square foot were also reduced below the numbers at the control station, except downstream from Fairmont, W. Va., where sludgeworms and midges, the only bottom animals present, were found in high numbers because of discharge of sewage and other organic wastes. The pH in the Fairmont area and at all downstream stations ranged from 3.6 to 4.9 during the study. At several stations, coal washing operations made the water black and blanketed the stream bed with coal fines, eliminating living areas for animals. Bottom sediments had an odor of coal and oil.

Figure 50, as a mechanism for data display, leaves room for improvement. Two methods of depicting data are shown on one figure and this tends to create confusion in interpretation. The circles are too close together and the effort would have been enhanced if bars had been used to show both kinds and numbers of organisms.

The numbers of animals per square foot are shown as the diameter of the circle. Often the scale may be omitted on similar figures because the intent is to show relative differences among stations. Some reporters use the diameter of the circle to depict their data while others may use the circle's area. An interesting relationship between circle area and diameter is shown in figure 51. The writer should make his display clear and nondeceptive.

The Cheat River is formed by Shavers Fork and Black Water River upstream from Parsons, W. Va. In Shavers Fork, 13 kinds of stream bed animals including those found only in clean healthy streams were col-

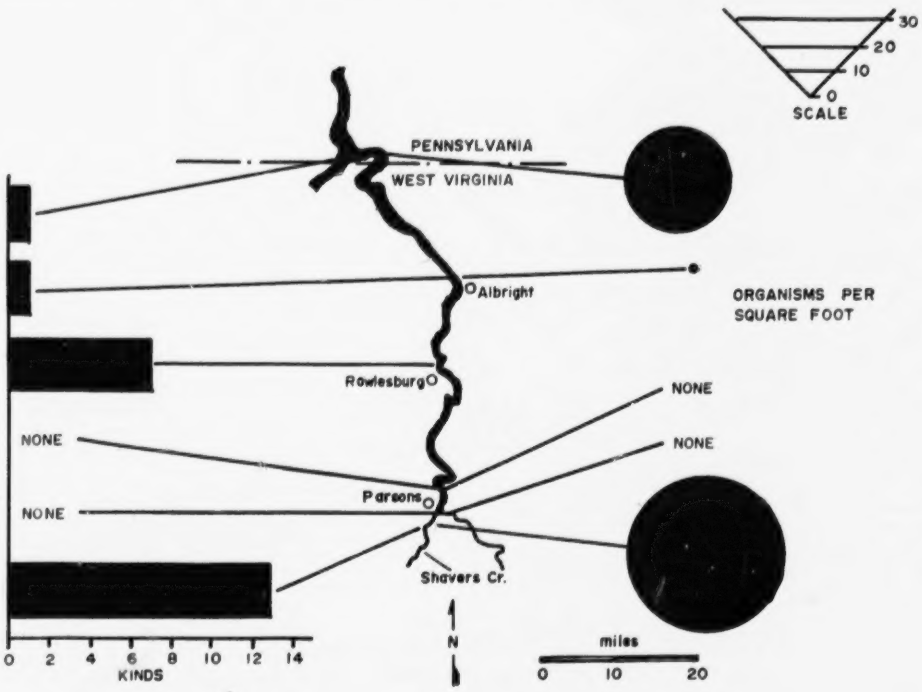

Figure 52. Stream bed animal data, Cheat River, 1953.

lected (figure 52). In Black Water River, stream bed rocks were coated with a reddish deposit characteristic of acid mine drainage and a tolerant alga; they supported no animals.

Downstream from Parsons, W. Va., no stream bed animals were found; those organisms that may have been introduced from Shavers Fork were killed. Some stream recovery was found at Rowlesburg, W. Va., where sampling was limited to a qualitative search because of the sheet rock stream bed. Downstream at Albright, the stream bed habitat was again severely degraded and only an occasional very tolerant organism could be found.

Plankton data confirm the conclusions drawn from a study of stream bed animals. Where conditions of existence were more stringent, and where stream bed animals were reduced in kinds and numbers, planktonic algae were likewise reduced severely in kinds and usually in numbers (figure 53).

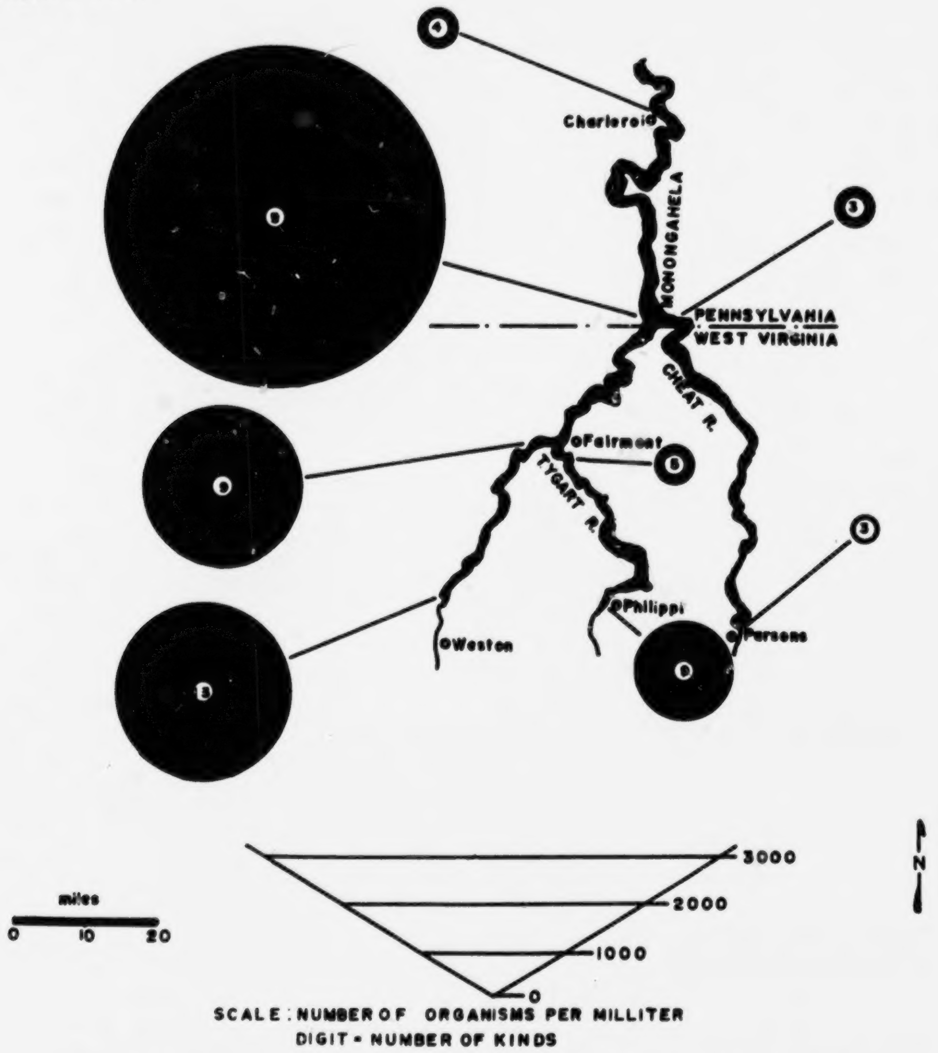
4
Charleroi
MONONGAHELA
3
PENNSYLVANIA
WEST VIRGINIA
CHEAT R.
Fairmont
6
TYGART R.
3
Philippi
Parsons
Weston
3000
2000
1000
0
miles
0
10
20
N
SCALE: NUMBER OF ORGANISMS PER MILLITER
DIGIT = NUMBER OF KINDS

Figure 53. Planktonic algal data, Monongahela River system, 1963.

9

RADIOACTIVE WASTES

KRUMHOLZ (1960) reports that radioactive materials may be accumulated by aquatic organisms in three different ways: (1) By ingestion along with water or food materials; (2) by absorption from the surrounding medium through the body surfaces; and/or (3) by adsorption to the body surfaces. The first two methods are largely biological in nature and the radionuclides enter into the metabolic processes of the organism. The third method is primarily physical in nature and the radio-materials adhere to outer body surfaces. In the latter instance, the size of the organism, because of the tremendous differences in surface-volume ratios of the different ones, is of great importance. In addition, the diversity of structure and surface configuration increase the surface area. Foster and Davis (1955) pointed out that the high radioactivities in plankton and sponges in the Columbia River were associated, in part, with their extensive surface areas.

Radioactive and stable isotopes of the same element have the same chemical behavior, and living organisms are not capable of distinguishing between the two. It is well known that all organisms do not concentrate all chemical elements, but that they select certain elements for their metabolic processes and discard others. Because of this selective power, it is to be expected that they will accumulate any radioactive isotopes of those elements that may be present along with the stable ones.

In an aquarium experiment, Whittaker (1953) showed how biological processes effectively removed phosphorus from the water with algae concentrating the tracer material to levels 300,000 times those in the water. During the first few hours after introduction, the phosphorus was absorbed rapidly by the phytoplankton, but after 15 hours the amounts of radioactivity in the phytoplankton decreased, and more and more of the radiophosphorus was accumulated by the algae on the sides and bottom of the aquaria. Maximum accumulations of radiophosphorus by the algae were reached in 18 days.

Davis, et al (1952, 1953) found concentration factors for radiophosphorus by phytoplankton in the Columbia River to be 100,000 to 200,000 times that of the surrounding water, and Krumholz (1954) reported that the attached freshwater alga (Spirogyra) concentrated radiophosphorus by a factor of 850,000 times that of the water in White Oak Lake.

From the culture of *Escherichia coli* cells in a phosphorus-poor medium containing 25 millicuries (mc) of phosphorus-32, and subsequent release into a small unpolluted stream, the release of the radioactive phosphorus (P^{-32}) downstream was investigated (Hooper and Ball, 1966). In moving downstream, approximately 90 percent of the radioactivity remained inside the bacterial cells while 10 percent diffused from the cells and appeared in the water in filterable form. There was a gradual loss of radioactivity from the water because of fallout of labelled cells and uptake by filter-feeding invertebrates. A small amount of the phosphorus-32 released in soluble form by the bacteria was taken up by the periphyton and by aquatic macrophytes. Failure to find important concentrations of radioactivity in any part of the food chain or in the environment suggested that *E. coli* cells effectively dispersed radioactive phosphorus and minimized the transfer activity through segments of the food web leading to man.

There is a general decrease in the level of radioactivity with the decrease in food chain level. Phytoplankton, which absorb nutrients directly from the water, concentrate the largest amounts. Next in order are the herbivorous insect larvae; and then juvenile fish, which feed on bottom organisms. Bass and other game fish, at the end of the food chain, are least radioactive. In a study of smallmouth bass in the Hanford, Washington, vicinity in the Columbia River, fish caught in September had the highest concentration of gross beta activity and fish caught in April the least (Foster and Henderson, 1957). The range in gross beta activity in units of 10^{6} microcuries per gram of tissue in September fish was 63 to 250 in skin and muscle, 310 to 3,520 in scales and bone, 98 to 840 in internal organs and 700 to 8,240 in stomach contents. Davis (1962) found the insects in the Columbia River within the Hanford Reservation to be many more times radioactive than the waters they inhabit. The most abundant nuclides found in insects were phosphorus-32, copper-64, chromiun-51, zinc-65, and sodium-24.

Echo and Hawkins (1966), in studying radionuclides in settling ponds, found that algae not only concentrated the radionuclides in their structure, but that the release of the nuclides might be retarded for considerable lengths of time, especially in waters of low pH. This might form a zone of high activity of undesirable magnitude at the mud-water interface.

Animas River

The Animas River rises in rugged mountains in the vicinity of Silverton in southwestern Colorado. It flows southerly for 50 miles to Durango, Colorado, and joins the San Juan River about 60 miles south and west of Durango, at Farmington, New Mexico. A uranium mill was located at Durango, approximately mid-way along the river. Upstream from Durango the river is narrow, flowing through mountainous terrain. Where the river flows through Durango it is from 100 to 200 feet wide and has an average depth, during low flow, of about 5 feet. Downstream the river meanders through farmland, then passes through a section of rocky outcrop where its width is restricted to about 150 feet, then again passes through more gentle terrain. Downstream the climate becomes progressively more arid.

The Animas is the domestic water supply for Aztec and Farmington, New Mexico, which had a combined population of 28,000. Downstream from Durango, the Animas provides water to irrigate 26,000 acres of croplands, as well as a recreational area including swimming and fishing.

The uranium refinery at Durango began continuous operation in 1948. Flows in the Animas River at Durango were 250 cfs in 1955 during sampling. Data indicated an approximate discharge of 2.0 milligrams per day of dissolved radium from the Durango refinery. Samples of mud, algae and bottom insects were analyzed in 1955 and again during the 1958 survey (table 6).*

Table 6. Radium 226 in Animas River Samples**

	Water pg/1	Sediment pg/g^1	Algae pg/g^2	Insects pg/g^2
1955:				
1 mi. upstream from Durango.......	0.2		6	6
2 mi. downstream from Durango....	3.3		660	360
1958:				
1 mi. upstream from Durango.......	0.6	1.7	4.8	4.2
2 mi. downstream from Durango....	12.6	115	390	71

1 dry weight
2 ashed weight

A copper wire screen with 14 wires per inch, one square yard in area, supported at 2 opposite sides by wood strips 1" x 2" x 4 ft. was used to sample bottom fauna in the rocky swiftly flowing stream in 1958. A 1-yd^2 area immediately upstream from the screen was sampled by wiping the organisms from the rocks and stirring up the bottom. Detached organisms were carried in the current and deposited on the screen. The screen was then lifted from the water and organisms removed with forceps and placed in marked vials.

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*Survey of Interstate Pollution of the Animas River, Colorado-New Mexico. U.S. Department of Health, Education, and Welfare, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, May, 1959.

**A picogram (pg) is 10^{-12} gram. In the case of radium, 1 gram very nearly equals 1 curie, where the curie is defined as 3.70×10^{10} disintegrations per second. Thus 1 picogram very nearly equals 1 picocurie or 1 micromicrocurie of radium.

Mill effluent flowed along one side of the river for some distance before becoming completely mixed with the receiving waters. No stream bed organisms were found on the waste receiving side and organisms were affected adversely in the center of the stream. A population of stream bed animals unaffected by pollution was found on the opposite side.

The scarcity of botton organisms extended for 28 miles downstream from the mill where only 14 insect larvae per square yard were collected in a 7 square yard sample. Forty-three miles downstream from the mill the numbers, kinds and weight of stream bed organisms were nearly equal to the collections upstream from the mill.

Bioassay tests were made to determine the toxicity of the wastes to rainbow trout, the most important game fish in the stream. Several acid waste streams had different toxicities; the most toxic wastes killed 50 percent of the test fish in 96 hours in dilutions containing only 0.09 to 0.21 percent of waste with receiving river water.

A report subsequent to the aforementioned one was dated January, 1960; it described stream studies conducted during the summer of 1959 that were designed to evaluate effects of remedial treatment facilities, principally waste lagooning, installed by the uranium mill during 1959. The mill's discharge of radium between 1958 and 1959 was reduced by 80 percent to 0.059 mg/day. In algae, river mud, and fish there was a definite reduction in dissolved radioactivity in 1959 compared to the earlier year. Just downstream from the pollutional source, river muds contained only 11 percent of the alpha radioactivity in 1959 for an 89 percent improvement over 1958. June high river flows were thought to be responsible for much of the decrease. Algae contained 30 percent of the gross alpha radioactivity value.

The bottom organism population was improved in 1959 in terms of variety of species, but was little improved, compared to 1958, in terms of abundance or weight per square yard of stream bed.

Sigler et al. (1966) have reported on their studies of the Animas River from June, 1960, to July, 1963. The uranium mill at Durango ceased operations in 1963. During 22 sampling trips, water samples contained concentrations of dissolved radium ranging from 0.3 to 2.2 pg/l with background values averaging 0.06 pg/l. In sediments, background radium concentrations were 1.1 pg/g dry weight and samples downstream from Durango ranged up to 27 pg/g in concentration. After May, 1961, sediment values higher than 5.6 pg/g were not found; this reduction was attributed to movement of radium downstream during high spring runoff by leaching, and the transport of radium-bearing biotic components and sediments.

Sigler et al. concluded that the concentration of radium in the water, sediment, algae, and fish of the Animas River decreased from 1958 to 1963. During 1960 to 1963, collections of aquatic organisms indicated that numbers and diversity of the biota downstream from Durango were similar to those found upstream. Occurrence or abundance of particular organisms varied among stations, but the reasons for such changes were not apparent.

An opportunity arose in 1966 to restudy this portion of the Animas River.* Then, the population of stream bed animals increased from 277 organisms per square yard upstream from Durango to 3,034 organisms per square yard, mostly clean water associated caddisfly larvae, a short distance downstream. Farther downstream, the population was again 230 organisms per square yard. The same sampling device and procedures were used in this survey as in the 1958 and 1959 surveys to make the data reasonably comparable. The sharp population increase downstream from Durango was a response to the organic enrichment in municipal waste discharges from Durango, and the removal of toxic uranium mill wastes. The organic enrichment was insufficient in volume and concentration to eliminate clean water associated organisms, instead, it stimulated the production of some of them.

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*A report on biological studies of selected reaches and tributaries of the Colorado River. U.S. Department of the Interior, Technical Advisory and Investigations Branch, Cincinnati, Ohio, prepared in cooperation with the Colorado River Basin Water Quality Control Project, Denver, Colo., 1968.

10

EUTROPHICATION

IT IS well documented that many lakes throughout the country, and the world, have been fertile reservoirs for algal development for many years and have been called eutrophic. Notable for their algal growths in the United States are Lake Zoar in Connecticut, Lake Sebasticook in Maine, the Madison Lakes in Wisconsin, Lake Erie, the Detroit Lakes in Minnesota, Green Lake and Lake Washington in Washington, and Klamath Lake in Oregon.

As nutrient concentrations increase the numbers of algal cells increase. Nuisance conditions occur such as surface scums and algal-littered beaches. The water may become foul smelling. Filter-clogging problems may occur at municipal water treatment installations. Filamentous algae, especially *Cladophora,* grow profusely on any suitable subsurface; these can cause nuisances when they break loose and wash ashore to form windrows of stinking vegetation. The abnormal acceleration of a process that is considered as normal often is not in the best interests of man.

To properly assess a nutrient problem, consideration should be given to all of those sources that may contribute nutrients to the watercourse. These sources could include sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and nutrients released from bottom sediments and from decomposing plankton. Transient waterfowl, falling tree leaves, and ground water may contribute important additions to the nutrient budget. Flow measurements are paramount in a study to quantitatively assess the respective amounts contributed by these various sources during different seasons and at different flow characteristics. In the receiving lake or stream the quantity of nutrient contained by the standing crops of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are harvested annually through the fish catch, or that may be removed from the system through the emergence of insects, will contribute to an understanding of the nutrient budget.

The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, minimal nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations are likewise important. Usually, it is necessary to determine that portion of the nutritive input attributable to man-made or man-induced pollution that may be corrected as opposed to that input that is natural in origin, and therefore, usually not correctable. A nutrient budget is used to determine the annual input to a system, the annual outflow, and that which is retained within the water mass to recycle with the biomass or become combined with the solidified bottom sediments. Examples of nitrogen and phosphorus inputs were presented in tables 2 and 3.

Reservoirs or lakes are the settling basins of drainage areas. The potential productivity of a body of water is determined to a great extent by the natural fertility of the land over which the runoff drains and by the contributions of civilization. Biological activity within the lake influences such chemical characteristics as dissolved oxygen, pH, carbon dioxide, hardness, alkalinity, iron, manganese, phosphorus, and nitrogen; it is varied through temperature fluctuations and stimulated by nutrient variations (e.g., phosphorus and nitrogen). A lake's basin gives dimension to biological activity and may, because of unique physical characteristics, concentrate the nutrients it receives as well as the developing biomass.

The examination of waterway sediments and other solids fits well in a discussion devoted to eutrophication. Sediments are best collected with a device that permits a core of the material to be extracted from which segments may be selected for examination. These identifiable segments may be examined for pollen, diatom skeletons or chitinized remains of cladocerans or midges, as well as selected chemical constituents. Generally carbon and nitrogen, and often phosphorus, are determined. The carbon, nitrogen, phosphorus, and their respective ratios are important values to aid in the identification of a material, to calculate the amount of major nutrients contained within a segment of the biomass or a stratum of sediment, and from which to judge the relative input of nutrients to the water mass when the ecosystem component undergoes decomposition, or natural chemical change (table 7).

Gerloff has been a proponent of a tissue analysis technique to evaluate nitrogen and phosphorus supplies in waters for growth of algae and angiosperm aquatic plants and to determine availability of the elements in lakes from which plants were collected (Gerloff and Krombholz, 1966). They found the critical levels (minimum tissue content associated with maximum growth) to be approximately 1.3 percent nitrogen and 0.13 percent phosphorus for several species of vascular plants. In all but 1 of 9 lakes studied, phosphorus was found more likely to be limiting to higher aquatic plant growth than was nitrogen. In Lake Mendota, Wisconsin, a highly fertile lake, plant samples were collected in June, July, August, and

Table 7. Carbon, Nitrogen, and Phosphorus in Freshwater Environmental Constituents

Constituent	Standing Crop, lbs/ac		%C[1]	%N[1]	%P[1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Phytoplankton	1,000 to 3,600	100 to 360						Birge and Juday, 1922.
				6.8	0.69		10	Gerloff and Skoog, 1954.
			39	6.1	0.64	6.5	10	Mackenthun et al., 1968.
				9.0	0.52		17	Birge and Juday, 1922.
Attached Algae	2,000	200						Neil, 1958.
				2.8	0.14		2	Birge and Juday, 1922.
Vascular Plants	14,000	1,800						Rickett, 1922, 1924.
				1.8	0.18		10	Harper and Daniel, 1939.
Myriophyllum				3.2	0.52		6	Birge and Juday, 1922.
Vallisneria				1.8	0.23		8	Schuette and Alder, 1928, 1929.
Potamogeton				1.3	0.13		10	Schuette and Alder, 1928, 1929.
Castalia				2.8	0.27		10	Schuette and Alder, 1928, 1929.
Najas				1.9	0.30		6	Schuette and Alder, 1928, 1929.
Myriophyllum				3.0	0.5		6	Anderson et al.,1965.
Bottom Organisms								
Midges	200 to 400	40 to 80						Dineen, 1953; Moyle, 1940.
Chironomus				7.4	0.9		8	Borutsky, 1939.
Hyalella				7.4	1.2		6	Birge and Juday, 1922.
Hirudinea				11.1	0.8		14	Birge and Juday, 1922.
Sialis				8.1	0.6		14	Birge and Juday, 1922.

Fish	150 to 600						Swingle, 1950.
			[2]2.5	[2]0.2		10	Beard, 1926.
			2.8	0.18 to 0.49			Borgstrom, 1961.
				0.19			Love et al., 1959.
				0.20			McGauhey et al., 1963.
				0.29			Sylvester and Anderson, 1964.
			2.6 to 3.3	0.18 to 0.24			Ingalls et al., 1950.
Domestic Wastes[3]				5.1 to [4]10.6			Engelbrecht and Morgan, 1959.
			[4]45	[4]8		6	McGauhey et al., 1963.
			20 to [4]40	5.3 to [4]10.6		4	Bush and Mulford, 1954.
			[4]61.3	[4]10.7		6	Oswald, 1960.
			18 to [4]28	3.5 to [4]9.0			Anon, 1967.
Sediments							
Lake Tahoe		0.6 to 19.8	0.6 to 1.6		4 to 25		McGauhey et al., 1963.
Wisconsin Lakes		4.4 to 40.5	0.6 to 3.6	0.12 to 0.6	8 to 14	5 to 6	Black, 1929; Juday et al., 1941.
Madison, Wis. Lakes			0.7 to 0.9	0.1 to 0.12		6 to 9	Sawyer et al., 1945.
Green Lake			0.6	0.17		4	Sylvester and Anderson, 1964.
Lake Sebasticook		10 to 34	0.3 to 1.8	.06 to .16	8 to 44	5 to 16	Mackenthun et al., 1968.
Klamath Lake		8.6	1.2		7		Thomas, N. A., Unpublished.[6]
Boston Harbor		2.3 to 5.0	.06 to .41				Stewart, R. K., 1968.[5]
Organic River Sediments		0.03	0.0027		12		Finger and Wastler, 1969.

[1] As the total element in percentage of the dry weight, unless specified otherwise

Constituent	Standing Crop, lbs/ac		%C[1]	%N[1]	%P[1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Pulp & Paper Wastes in River			5.3	0.23		22		Finger and Wastler, 1969.
Untreated Domestic Wastes			3.54	0.3		12		Finger and Wastler, 1969.
Untreated Chemical and fertilizers and domestic wastes			3.15	0.12		26		Finger and Wastler, 1969.
No tributary wastes			0.55	0.05		11		Finger and Wastler, 1969.
Sand; silt; clay; loam			0.4 to 2.1	.02 to .10		20		Ballinger and McKee, Unpublished.[6]
Stable sludge; peat; organic debris			2.0 to 5.0	.10 to .20		20 to 25		Ballinger and McKee, Unpublished.[6]
Paper mill wastes			6 to 15	.10 to .30		50 to 60		Ballinger and McKee, Unpublished.[6]
Packinghouse Wastes			2.8 to 4.3	.30 to .50		8 to 10		Ballinger and McKee, Unpublished.[6]

Fresh sludge; decaying algae; sewage solids	5 to 40	.70 to 5.0		7 to 8		Ballinger and McKee, Unpublished.[6]
Log Pond Bark	50.6	.5	.02	100	25	Thomas, N. A. Unpublished.[6]
Sewage sludge in river	5.8	0.28	.18	21	2	Thomas, N. A. Unpublished.[6]
Algae; sawdust; sewage	14.6	0.93	.11	16	9	Thomas, N. A. Unpublished.[6]
Leaf litter	28.3	1.63	0.11	17	15	Warner, R. W. et al., 1969.[7]
Sand	0.2	.02	.005	10	4	Warner, R. W. et al., 1969.[7]
Loam	2.7	.19	.02	14	10	Warner, R. W. et al., 1969.[7]
Muck	7.3	.52	.04	14	13	Warner, R. W. et al., 1969.[7]
Floating Waste Wool	37 to 43	3.4 to 4.7	.08 to .09	9 to 11	38 to 58	[8].

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[1] As the total element in percentage of the dry weight, unless specified otherwise.

[2] Calculated on wet weight.

[3] Average sewage flow can be calculated at 100 gallons per capita per day.

[4] mg/1

[5] Biological Aspects of Water Quality, Charles River and Boston Harbor, Massachusetts by R. K. Stewart. Technical Advisory and Investigations Branch, Cincinnati, Ohio (1968).

[6] Technical Advisory and Investigations Branch, Cincinnati, Ohio.

[7] Analyses of soil types from "Black-Water Impoundment Investigations," by R. W. Warner, R. K. Ballentine and L. E. Keup, Technical Advisory and Investigations Branch, U.S. Department of the Interior, Cincinnati, Ohio (1969).

[8] Fertilization and Algae in Lake Sebasticook, Maine. Department of Health ,Education, and Welfare, Technical Advisory and Investigations Activities, Cincinnati, Ohio (1966).

September. The percentage of nitrogen in plant tissues of *Ceratophyllum demersum* varied from 2.11 to 4.43 among these monthly samples while percentage phosphorus varied between 0.51 and 0.75. Among 6 plant species, the percentage of nitrogen varied from 1.98 to 4.43 and phosphorus from 0.23 to 0.75. In Lake Nebish, Wis., a relatively infertile lake, the variance among 4 plant species among the same months was 1.48 to 3.19 percent nitrogen and 0.10 to 0.33 percent phosphorus.

The carbon-nitrogen and nitrogen-phosphorus ratios are of greater value in data interpretation than are total to soluble phosphorus ratios. Total to soluble phosphorus ratios may vary from 2 to 17 or even 90 percent dependent upon the particular water, season, aquatic plant populations, and probably other factors (Table 8). These ratios are of value when they can be determined periodically within the same water body and changes in them correlated with volumetric response changes within the algal mass.

Table 8. Total to Soluble Phosphorus Ratios in Water

Water	Total P:Sol.P	Reference
Western Lake Erie................	3.5	Chandler and Weeks, 1945.
Detroit River mouth..............	5 to 7	PHS Detroit Project.
Linsley Pond, Conn...............	10.0	Hutchinson, 1957.
Northern Wisconsin Lakes........	7.0	Juday and Birge, 1931.
Northeast Wisconsin Lakes.......	2 to 10	Juday et al., 1927.
Ontario Lakes (8).................	17	Rigler, 1964.
Southeast Wisconsin Lakes (17)...	9	Mackenthun, unpublished.
Rock River, Wis...................	2 to 15	Mackenthun, unpublished.
Sebasticook Lake, Maine..........	2.8 winter	Mackenthun et al. 1968.
Do............................	12.7 spring	Do.
Do............................	7.0 summer	Do.
Do............................	4.1 fall	Do.

The nutrient loading to the lake on a unit basis gives some measure of comparability among various water bodies (table 9). Likewise, a lake or reservoir usually retains a portion of those nutrients that it receives from its various sources. The amount or percentage of the nutrients that may be retained by a lake or reservoir is variable and will depend upon:

1. the nutrient loading to the lake or reservoir;
2. the volume of the euphotic zone;
3. the extent of biological activity;
4. the detention time within the basin or time allotted for biological activity; and
5. the level of the penstock or discharge from the basin.

Lake Sebasticook, Maine

Lake Sebasticook at Newport, Maine,* was plagued with nuisance algal growths caused principally by nutrients contained in domestic and in-

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* Fertilization and Algae in Lake Sebasticook, Maine. Technical Advisory and Investigations Activities, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 1966.

Table 9. Lake Nutrient Loadings and Retentions

Lake	State	Nitrogen (N)		Phosphorus (P)		Reference
		Loading lb./yr./acre	Retention (Percent)	Loading lb./yr./acre	Retention (Percent)	
Washington	Wash.	280		12		Anderson, 1961.
Mendota	Wis.	[1]20		[2]0.6		Anon., 1949.
Monona	Wis.	[1]81	48 to 70	[2]7.5	64 to 88	Lackey and Sawyer, 1945.
Waubesa	Wis.	[1]435	50 to 64	[2]62.8	−26 to 25	Do.
Kegonsa	Wis.	[1]162	44 to 61	[2]35.9	−21 to 12	Do.
Tahoe	Calif.	2	89	0.4	93	Ludwig et al., 1964.
Koshkonong	Wis.	90	80	40	30 to 70	Mackenthun, unpubl.
Green	Wash.			4.8	55	Sylvester and Anderson, 1964.
Geist	Ind.	[1]440	44	28	25	F.W.P.C.A. Data.
Sebasticook	Maine			2	48	Do.
Ross R. Barnett	Miss.			32		Do.

[1] Inorganic nitrogen only. [2] Soluble phosphorus only.

dustrial plant wastes that were discharged to the East Branch of the Sebasticook River at Dexter and Corinna, Maine. Along with other nutrients, the Lake received annually about 8,000 pounds of total phosphorus, 75 percent of which was contributed by domestic and industrial wastes. These nutrients produced as much as 9.7 million pounds of algae as a standing crop within the lake during those days of the year that were optimal for algal development. Algae were swept by winds and waves into bays and coves where they decomposed in the hot sun forming a "green-paint" covering on rocks, boats, and piers, releasing a pungent pig-pen odor in decay.

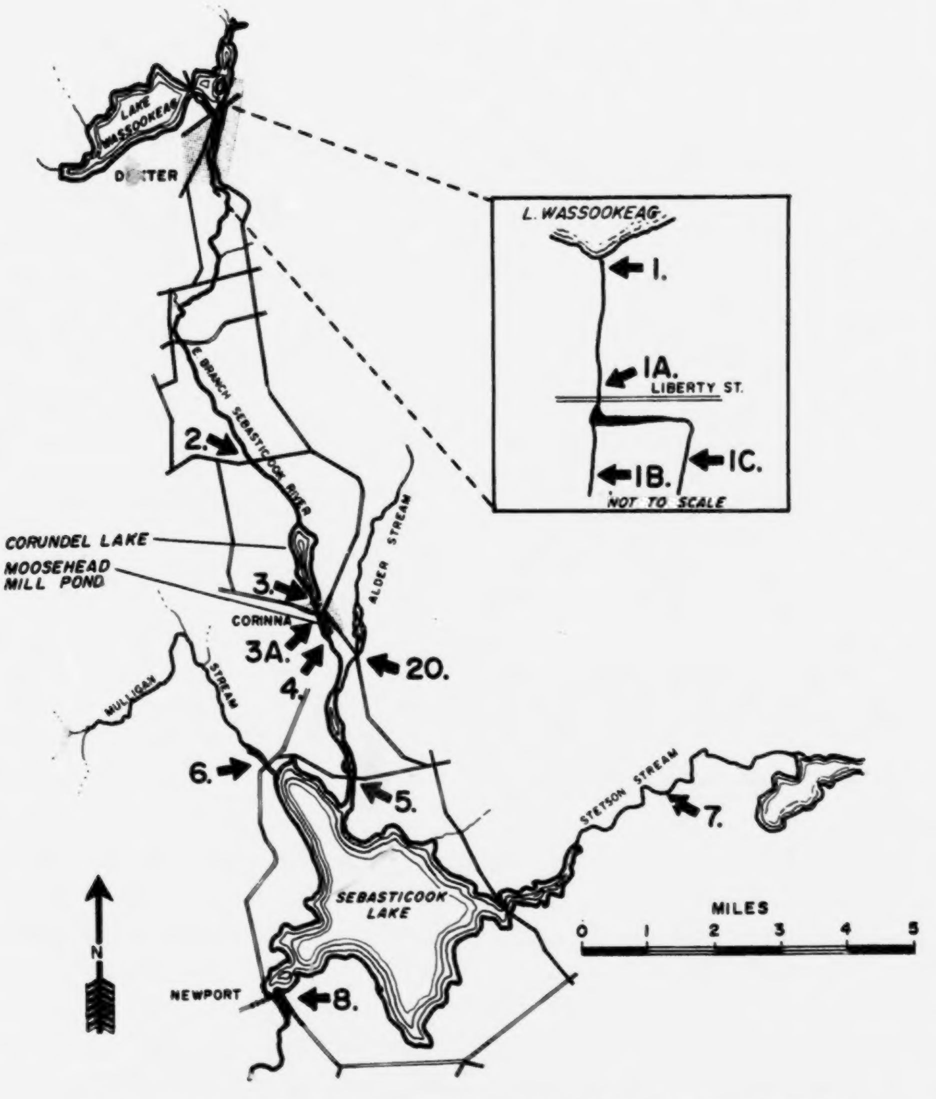
The field study, made in 1965, encompassed the East Branch of the Sebasticook River from Lake Wassokeag to the inlet of Lake Sebasticook (a distance of 10.5 stream miles); Alder Stream, tributary to the East Branch; Stetson and Mulligan streams, tributary to Lake Sebasticook (fig. 54); Lake Sebasticook (fig. 55); and the lake's outlet. The purpose of the study was: (1) to identify major sources of nutrients to Sebasticook Lake; (2) to assess their significance; and (3) to recommend the most feasible nutrient control measures that will effect a lasting reduction in the aquatic growths. Field studies were conducted during the winter ice-cover in early February, just following the spring lake turn-over from May 11 through 18, the summer maxima of aquatic vegetation growth from July 26 to August 2, and the fall lake turn-over during the last week of October and the first week of November.

Samples for analyses for nitrogen (organic-N, NH_3-N, NO_3-N) and for total and dissolved phosphorus were fixed with 1 ml H_2SO_4 per liter and shipped to Cincinnati, Ohio, in polyethelene containers. Samples for dissolved phosphorus analysis were filtered shortly after collection and shipped separately. Analytical procedures were according to Standard Methods for the Examination of Water and Wastewater (Twelfth Ed.).

Field collections of water for plankton analyses were preserved with 4 percent formalin and shipped to the Cincinnati laboratory. Phytoplankton counts were made using the Sedgwick-Rafter counting cell following Standard Methods for the Examination of Water and Wastewater. Microscopic measurements were made of a selected number of predominant organisms and the wet algal volume was determined by the following formula:

> Algal volume (p.p.m.) = Number of organisms per millileter × average species volume in cubic microns × 10^{-6}.

Chlorophyll bearing cells were filtered from the water with membrane filters (0.45 micron pore). Filters and cells were placed in vials of acetone for extraction of the pigments and for solution of the filters (Creitz and Richards, 1955). Samples were then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone was examined on a recording spectrophotometer. Spectrums were eval-


LAKE WASSOOKEAG
DEXTER
L. WASSOOKEAG
1.
1A.
LIBERTY ST.
1B.
1C.
NOT TO SCALE
E. BRANCH SEBASTICOOK RIVER
2.
CORUNDEL LAKE
MOOSEHEAD MILL POND
3.
CORINNA
3A.
4.
ALDER STREAM
20.
MULLIGAN STREAM
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STETSON STREAM
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Figure 54. Sampling station locations on tributary streams, Lake Sebasticook, Maine.

uated and the quantity of cholorophyll determined as outlined by Richards with Thompson (1952).

An aliquot solids sample based on a packed volume of a selected core segment was oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) were added, the mixture cooled, washed into a centrifuge tube, and water added. The sample was washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue was then diluted to a specific volume of water (200 ml per gram of original sample), 2 drops of liquid household detergent were added, the sample stirred, and 2 drops of sample were withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover

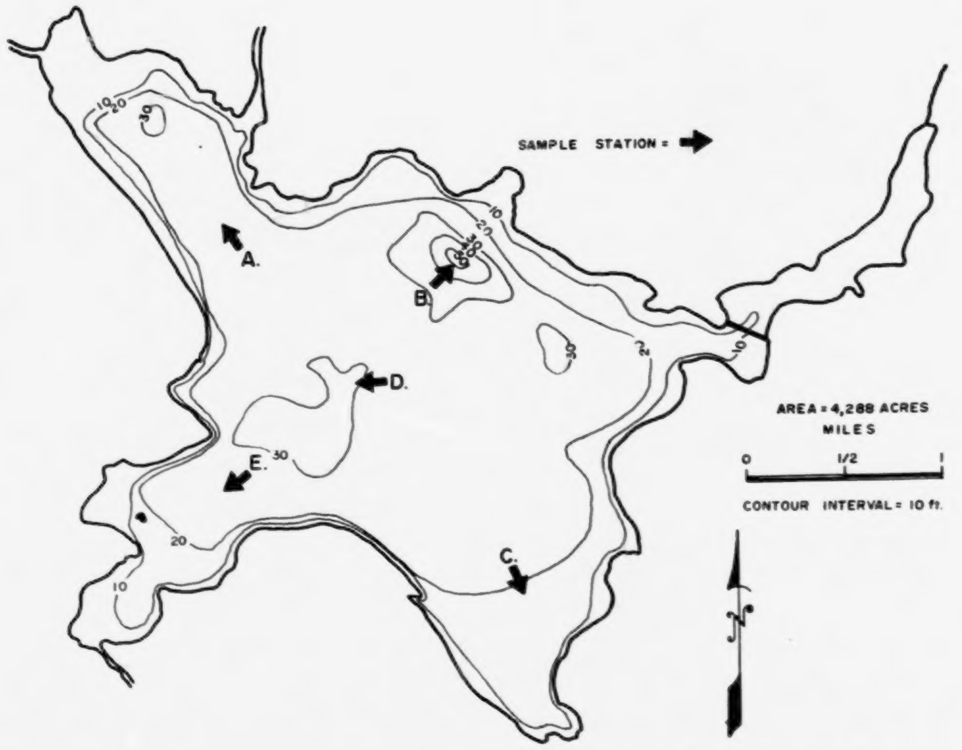

Figure 55. Sampling station locations on Lake Sebasticook, Maine.

slip was evaporated to dryness on a hot plate. Following dryness the hot plate temperature was increased to 350° F., a clean microscopic slide was placed thereon, and a large drop of Hyrax mounting media was placed on the slide. After 10 minutes, and slight cooling, the cover slip with dried sample was inverted onto the Hyrax drop and pressed firmly into place. The slide was then examined for diatom skeletons.

The Sebasticook Lake drainage basin has an area of 126 square miles. The lake is fed by runoff from three main tributary streams: Mulligan Stream having a drainage area of 20.9 square miles, the East Branch of the Sebasticook River, with a drainage area of 56.2 square miles, and Stetson Stream, with a drainage area of 28.6 square miles. About 8,600 people resided in the area.

Mulligan and Stetson streams drained rural areas which were sparsely populated. There were no known significant nutrient waste discharges to these streams. The East Branch of the Sebasticook River received discharges of municipal and industrial wastes from the urban portions of the Towns of Dexter and Corinna. The river received wastes from 2 woolen mills in Dexter that produced woolen yard goods from raw stock, which had been scoured prior to receipt. Wastes consisted of batch dumps of spent washing and dyeing solutions and large volumes of rinse waters. Another woolen mill discharged wastes downstream at Corinna, Maine. Also near Corinna, a potato canning company discharged phosphorus-rich wastes from the processing of 170 to 190 tons of potatoes daily during 9 to 10 months of the year.

The East Branch of Sebasticook River from Corinna, Maine, to the inlet of Lake Sebasticook was severely polluted. Dye wastes colored the water purple, and luxuriant growth of aquatic slimes, wool fiber mats, potato sprouts, and rotting potatoes were visible in certain areas. Downstream, this reach divides naturally into three ponded areas totaling 167 acres that serve as waste stabilization sites. Floating masses of wool dotted the surface of these waters and rising gas bubbles from decomposition pockmarked the stream reach. The discharge from the downstream waste stabilization site is the principal inlet to Lake Sebasticook.

Results of 1,400 nitrogen and phosphorus analyses showed that total nitrogen added to Sebasticook Lake by the East Branch of the Sebasticook River ranged from 445 to 778 lb./day during the 4 survey periods, and total phosphorus ranged from 15 to 30 lb./day during the February, May, and October surveys. Only 9.3 lb./day of total phosphorus were added during the July survey, when the potato-canning company was not in operation. In the Corinna area, about 85 percent of the nitrogen contributions came from the woolen mill, and 55 percent of the phosphorus discharged to the stream was from the canning company. Of all nitrogen and phosphorus sources to Lake Sebasticook, the East Branch of the Sebasticook River was the principal contributor because of discharges of municipal and industrial wastes (Mackenthun et al., 1968).

Within one-half mile of Sebasticook Lake, 16,700 lb./yr of phosphorus were contained in the fertilizers applied to 230 acres of agricultural lands that grow potatoes, apples, alfalfa, beans, and corn. Some of these nutrients, perhaps 100 lb./yr, reached the lake and contributed to the algal problem. This was approximately 0.6 percent of the phosphorus applied to the agricultural soils and less than 2 percent of the annual total phosphorus entering Lake Sebasticook.

Waste disposal facilities for 269 shoreline dwellings included 190 septic tanks and 79 privies. Assuming 4 persons per dwelling with an average occupancy of 3 months, the population equivalent on an annual basis was 269 and the contribution of total phosphorus was 800 lb. Many private wastewater disposal units either were located or discharged only 20 ft or less from the waters of Lake Sebasticook and thus contributed between 5 and 10 percent of the total phosphorus load to the lake.

The soil and subsoil as well as the underlying strata through which underground water passes are natural sources of lacustrine phosphorus. Eight shallow wells and one spring located on the shores of Sebasticook Lake were analyzed for nitrate-nitrogen and total phosphorus. With the exception of a 38-ft artesian well with 3.45 mg/l, the NO_3-N in these well samples did not exceed 0.04 mg/l. The total phosphorus in one well was 0.07 mg/l, in an 18-ft deep well and a 2-ft deep spring it was 0.02 mg/l, and in the remaining wells was 0.01 mg/l or less.

Lake Sebasticook lies in a forest transition zone between the spruce-fir and northern hardwoods forests. Tamarack, eastern hemlock, white pine, spruce, balsam fir, maples, beech, black ash, and quaking aspen abound. The amount of nitrogen from pollen may be as high as 2 to 5 pounds per acre per year in a forested area (McGauhey et al., 1963). Pollen contains phosphate in addition to nitrogen, but pollen is known to remain essentially intact in the sediments and it cannot be assumed that these materials are released to the lake water. Likewise, about 20 pounds of nitrogen and 2 pounds of phosphorus per acre are returned annually to the soil by forest tree leaves (Donahue, 1961). The amounts of these materials reaching Lake Sebasticook would depend upon the leaching of soluble materials to the lake from adjacent leaf litter and that direct contribution arising from wind-blown leaves. This amount would be expected to be small in comparison to the total nutrient loading to the lake.

Vertical water temperatures and dissolved oxygen concentrations were taken during the May, July, and November studies from the deepest portion of the lake (fig. 56). The May study was conducted just following the spring overturn, and the November study was conducted during the fall overturn when the entire water volume of the lake was being mixed by winds. Dissolved oxygen was present from surface to bottom and especially during November the temperature did not vary from surface to bottom.

During the latter part of July, Lake Sebasticook was stratified. The thermocline began at a depth of 32 feet and extended downward to 44 feet. The dissolved oxygen was less than 1 mg/l at the beginning of the thermocline and was zero at a depth of 35 feet. The dissolved oxygen curves for the afternoon of July 29 and the morning of July 30 have a different profile in the upper waters and reflected the effects of the large mass of algae that was present at this time.

Analyses for organic N, NH_3-N, NO_3-N, total P, and soluble P were made on 820 water samples collected vertically at 10-ft intervals from 5 stations within the lake (fig. 55). During February, maximum ammonia nitrogen and organic nitrogen concentrations combined to make total nitrogen values of 3.3 mg/l in the surface waters and 6.2 mg/l in the profundal waters. Total phosphorus was stratified with depth; it was 0.05 mg/l in the surface waters and 0.37 mg/l in the profundal waters. Soluble phosphorus was 0.011 mg/l in the surface waters. During spring and summer, the total nitrogen decreased to about half of the February values; however, the inorganic nitrogen exceeded 0.3 mg/l at all depths and was greater than 0.45 mg/ in the surface waters. Total phosphorus was 0.05 mg/l in the surface waters in May and 0.06 to 0.07 mg/l in summer. Soluble phosphorus concentrations were 0.004 in autumn. Considering the four seasons, there was no reduction in nitrogen passing through the lake.

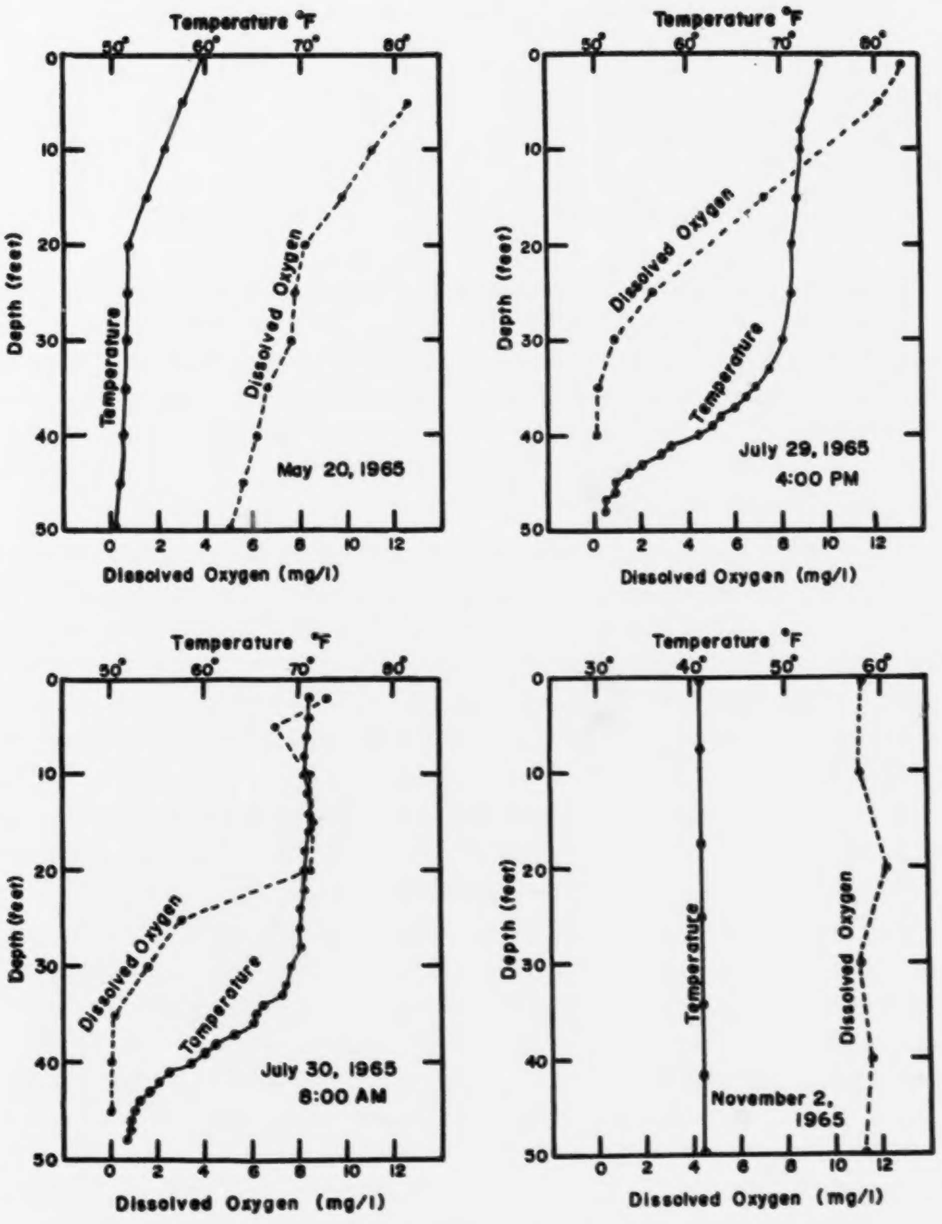

Figure 56. Vertical temperature and dissolved oxygen curves, Lake Sebasticook, Maine

Total phosphorus in the lake was most abundant during the summer (table 10). During the autumn and winter seasons the phosphorus was at the annual minimum. The ratio of total to soluble phosphorus was 2.8 in February, 12.7 in May, 7.0 in August, and 4.1 in November; this variation may be attributed to changes in amounts of algal growth during the different seasons. If the 4 sampling periods are representative of the 4 seasons of the year, the lake received 8,000 lb of total phosphorus annually; it dischargd 4,150 lb and retained 48 percent of the phosphorus. The period of water detention in the lake was calculated to average 3.5 yr.

Table 10. Nutrient and Algal Quantities in Lake Sebasticook, Maine, 1965

Pounds	February	May	August	November
Algae (wet) ($\times 10^6$)	2.29	2.70	4.4–9.7	2.46
Total P ($\times 10^3$)	9.2	11.4	14.8	9.1
Soluble P ($\times 10^3$)	3.3	0.9	2.1	<2.2
Organic N ($\times 10^3$)	390	222	197	197
Inorganic N ($\times 10^3$)	321	109	89	25

Phytoplankton counts in the surface waters of the lake ranged from 600/ml in February to 212,000/ml during a bloom on August 1. The volume of the algal mass varied between 15 and 19 p.p.m. in the surface waters except during the summer study, when 48 p.p.m. and 560 p.p.m. were recorded. The wet weight of phytoplankton per surface area was calculated to be 530 lb./acre in February, 630 in May, 1,000–2,260 in August, and 570 in November.

In the stabilization area, just upstream from the lake inlet, the quantity of chlorophyll *a* increased gradually toward the inlet of Lake Sebasticook (fig. 57). The grossly polluted water entering this area supported very few algae. As this water became less polluted through the setting of suspended solids and the decomposition and stabilization of organic materials, algae increased in numbers as nutrients became available from decomposing wastes.

A 19-inch sediment core was collected from a depth of 53 feet in Lake Sebasticook. Segments of the core were oven dried and analyzed for the percentage of carbon, nitrogen and phosphorus (table 11).

The dry weight phosphorus (P) in the 0–1 inch stratum was 0.15 percent. Assuming the lake bed sediments contain 15 percent solids, the upper 1-inch stratum of Lake Sebasticook just beneath the mud-water interface might then contain about 200,000 pounds of phosphorus. The 1–2 inch stratum contained 0.09 percent phosphorus or about 120,000 pounds for the entire lake—some 80,000 pounds less phosphorus than the inch immediately above it. The 2–3 inch stratum contained 0.06 percent or about 80,000 pounds of phosphorus. Beneath the 1–2 inch stratum the phosphorus content ranged from 0.06 to 0.09 percent on a dry weight basis.

Several 1-inch segments of the core were examined microscopically to enumerate diatom fragments and complete skeletons (table 12). Diatom shells or skeletons are composed of siliceous minerals that resist decomposition. Beginning at the mud-water interface with the most recent deposition and proceeding downward within the sediments, two periods occurred within the examined history of the lake when the diatom population increased at a rapid rate. This phenomenon would be expected during periods of accelerating enrichment. These periods occurred during the time between deposition of the 1–2 and 4–5-inch strata, and earlier between deposition of the 7–8 and 11–12-inch strata. The periods appear

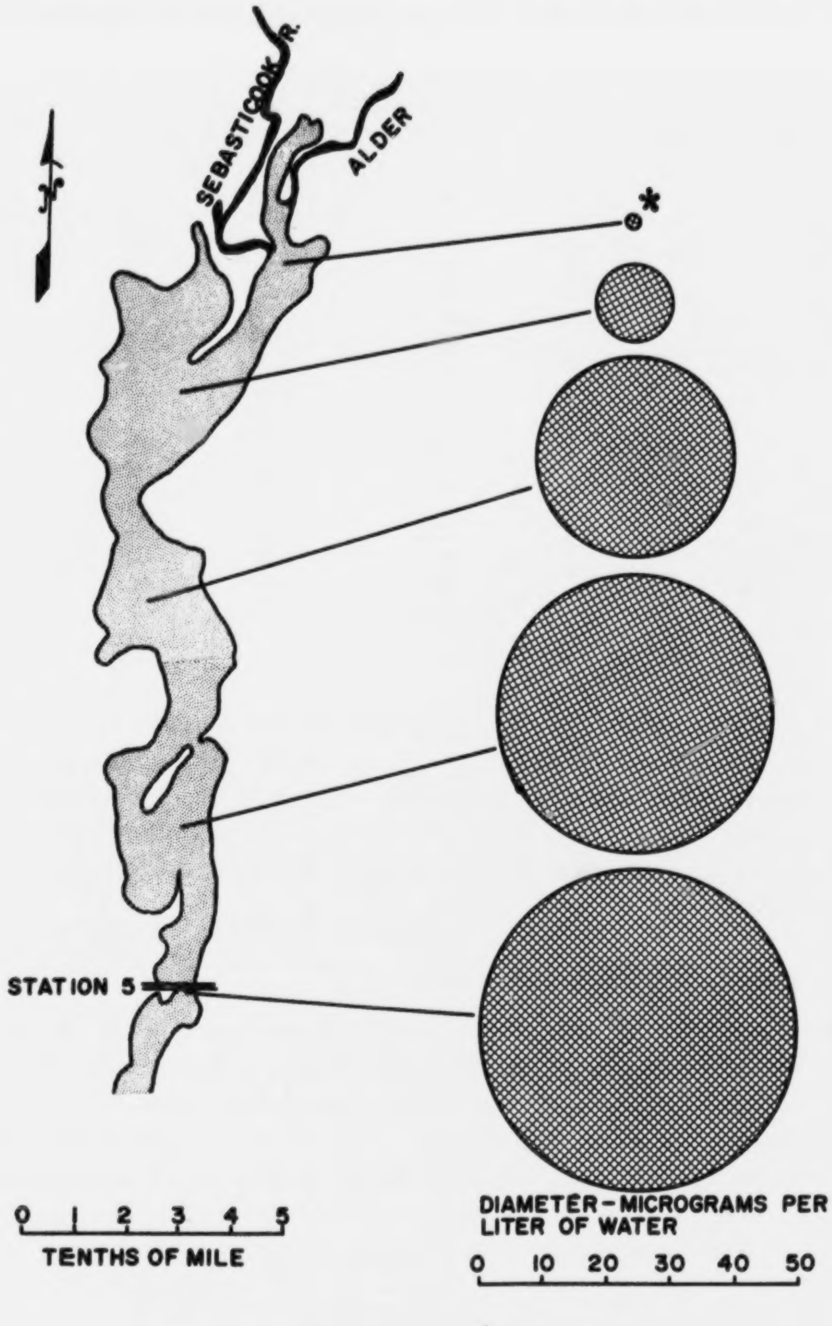
SEBASTICOOK R.
ALDER
STATION 5
0 1 2 3 4 5
TENTHS OF MILE
DIAMETER-MICROGRAMS PER LITER OF WATER
0 10 20 30 40 50
*LESS THAN

Figure 57. Chlorophyll entering Lake Sebasticook, July 29, 1965.

to be separated by years when the diatom production was less phenomenal.

The kinds of diatoms found are also indicative since different species attain abundance in different types of water. Those kinds predominating in the upper Lake Sebasticook sediments were: *Stephanodiscus astraea*

Table 11. Organic Carbon, Nitrogen, and Phosphorus in Sediments Lake Sebasticook, 1965

Lake sediment core	Percent dry weight Carbon	Percent dry weight Nitrogen	Percent dry weight Phosphorus	C:N	N:P
Inches:					
0–1	11.0	0.6	0.15	18	4.0
1–2	6.5	0.5	0.09	13	5.6
2–3	4.0	0.4	0.06	10	6.7
3–4	3.0	0.5	0.06	6	8.3
4–5	4.0	0.3	0.06	13	5.0
5–6	3.7	0.3	0.06	12	5.0
6–7	3.2	0.3	0.09	11	3.3
7–8	1.0	0.3	0.06	3	5.0
8–9	1.5	0.1	0.07	15	1.4
9–10	1.3	0.2	0.09	7	2.2
10–11	1.0	0.2	0.08	5	2.5
11–12	1.3	0.4	0.07	3	5.7
12–13	1.3	0.4	0.07	3	5.7
13–14	1.4	0.1	0.08	14	1.3
14–15	0.9	0.1	0.08	9	1.3
15–16	1.1	0.3	0.08	4	3.8
16–17	1.1	0.1	0.09	11	1.1
17–18	1.4	0.1	0.08	14	1.3
18–19	1.1	0.2	0.09	6	2.2

(Ehr.) Grunow apud Cleve and Grunow, *Melosira italica* (Ehr.) Kutzing, *Fragilaria crotoensis* Kitton, and *Asterionella formosa* Hassall. These same species were found in the upper sediments of much-studied, eutrophic Linsley Pond in Connecticut (Patrick, 1943). Patrick records that these species are characteristic of and reach their best development in eutrophic waters.

Lake Tahoe, California-Nevada

Lake Tahoe, astride the California-Nevada state line in the Sierra Nevade Mountains, is one of the clearest, deepest freshwater lakes in the world. Situated at an elevation of 6,225 feet, Lake Tahoe is 192 square miles in area (122,880 acres) and has a length of 21.6 miles and a width of 12 miles. The lake's maximum depth is 1,645 feet; its mean depth is 990 feet, and its volume is approximately 122 million acre feet. The 1,200-foot depth contour is often less than a mile from the nearest shore,

Table 12. Diatom Remains in Lake Sebasticook Sediments

Segment core (depth in inches)	Diatom particles (millions per gram)
1–2	326.4
4–5	54.8
5–6	47.4
6–7	45.8
7–8	40.2
8–9	22.3
9–10	7.7
11–12	2.7
18–19	0.1

and never more than three miles. The Tahoe drainage basin is 506 square miles.

At the present time,* the waters of Lake Tahoe are not enriched, nor do they support dense algal populations. Threats of future problems are serious, however. The phosphorus concentration in some near-shore areas is now at a critical level for the stimulation of algal growths, and all of the phosphorus present as shown by analytical tests is available for algal utilization. Available nitrogen concentration is presently low and is believed to be the major nutrient limiting algal development beyond the lake's present capacity. Potentially nuisance-producing blue-green algae and filamentous green algae are now present in some near-shore areas of the lake. Furthermore, the impact of nutrients from inflowing streams on the lake water was demonstrated by increased phosphorus concentrations and, in some cases, increased algal concentrations. Presently, this impact is limited to the near-shore waters surrounding the stream's mouth.

Temperature data indicate that the lake stratifies and that a thermocline occurs at a depth of 50 to 70 feet during summer months. Complete overturn has not been observed but may occur during winters of unusual severity.

Observations have been made on water transparency by viewing a white disc, approximately 8 inches in diameter, as it was lowered in the water. The white disc was observed to a depth of 136 feet at one station on April 4, 1962. This may be compared to a transparency value of 5 feet, or less, in a eutrophic lake with a heavy algal bloom. A minimum transparency of 49 feet, associated with a relatively high concentration of plankton, was observed in Tahoe's Emerald Bay on May 21, 1962. Although transparency measurements have been made on several occasions during the past 90 years by different investigators, no significant long-term trend can be detected.

Two of the major nutrients, nitrogen and phosphorus, are always of interest in connection with lake investigations because of their role in biotic production and in nuisance plant growths. Samples were analyzed from 12 offshore sampling points and 45 near-shore points for nitrate nitrogen (N) and soluble phosphorus (P) during both May and July. Nitrate nitrogen was present in an average concentration of 9.2 μg N/1 in May and 8.0 μg N/1 in July in the offshore areas, and 6.4 μg N/1 during both months at near-shore stations. Concentrations of ammonia nitrogen, nitrite nitrogen and organic nitrogen were below the analytical limits. The average concentration of soluble phosphorus was 5.1 and 10.9 μg P/1 in May and July respectively in the offshore areas and 6.1 and 8.7 μg P/1 in May and July respectively in the near-shore areas. No significant difference between concentrations of soluble and total phosphorus was found, indicating that all phosphorus was in the soluble form.

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* Report on Pollution in the Lake Tahoe Basin, California-Nevada by A. W. West and K. M. Mackenthun in cooperation with the Southwest Regional Office, San Francisco, Calif., U.S. Department of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio, July 1966.

Thirty-nine samples were collected from a depth of about 100 feet for plankton and chlorophyll determinations. Essentially all of the phytoplankton were diatoms. All counts were less than 500 organisms per ml with the exception of some near-shore areas. The Tahoe City boat harbor had 1,260 organisms per ml in April and 3,890 in July; both are considered algal blooms.

At the time that phytoplankton collections were made, water samples were analyzed for chlorophyll. Although chlorophyll *a* concentrations are considered low with a maximum July concentration of 1.74 mg/m^3, areas where chlorophyll *a* concentrations are greatest are located principally around the south and east near-shore (figure 58). Other areas of the lake have values less than 0.3 mg/m^3.

Organisms that are able to attach themselves to the surface of an object were studied by means of microscopic glass slides that were suspended in the lake water at different depths and removed at weekly intervals and examined microscopically. Bacteria outnumbered all other organisms and in some cases were the only organism found.

Although organisms of the type that produce objectionable growths such as filamentous algae, including blue-greens, are already present in near-shore areas, they are not now excessive because of low nutrient concentrations and a resulting low growth rate.

Lake Michigan

In a biological study of Lake Michigan* it was found that massive areas along the perimeter of the southern half of the lake were polluted to such an extent that large populations of pollution-tolerant sludgeworms occurred. The 2,100-square-mile area classified as polluted in figure 59, extending from Chicago northeastward around the southern tip of Lake Michigan, resulted from organic nutrients discharged by the large metropolitan areas bordering the lake. Lake sediments supporting populations of sludgeworms greater than 100 per square foot (approximately 1,000 per square meter) are considered polluted. Other areas with polluted lake bed sediments occurred in Green Bay, adjacent to the shorelines of Manitowoc, Sheboygan, Port Washington to Waukegan, and between Ludington and Manistee. Despite generally higher sludgeworm densities in inshore areas, the average number of organisms was depressed in a narrow band along the Chicago and Indiana shoreline. This was probably a result of wave action in the inshore areas which did not allow the settling of fine organic particles.

The waters of Chicago Harbor, Calumet Harbor and Indiana Harbor each contained excessive amounts of algal-stimulating nutrients. In Chi-

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* Lake Michigan Basin Biology, Federal Water Pollution Control Administration, Great Lakes Region, Chicago, Ill., January 1968.

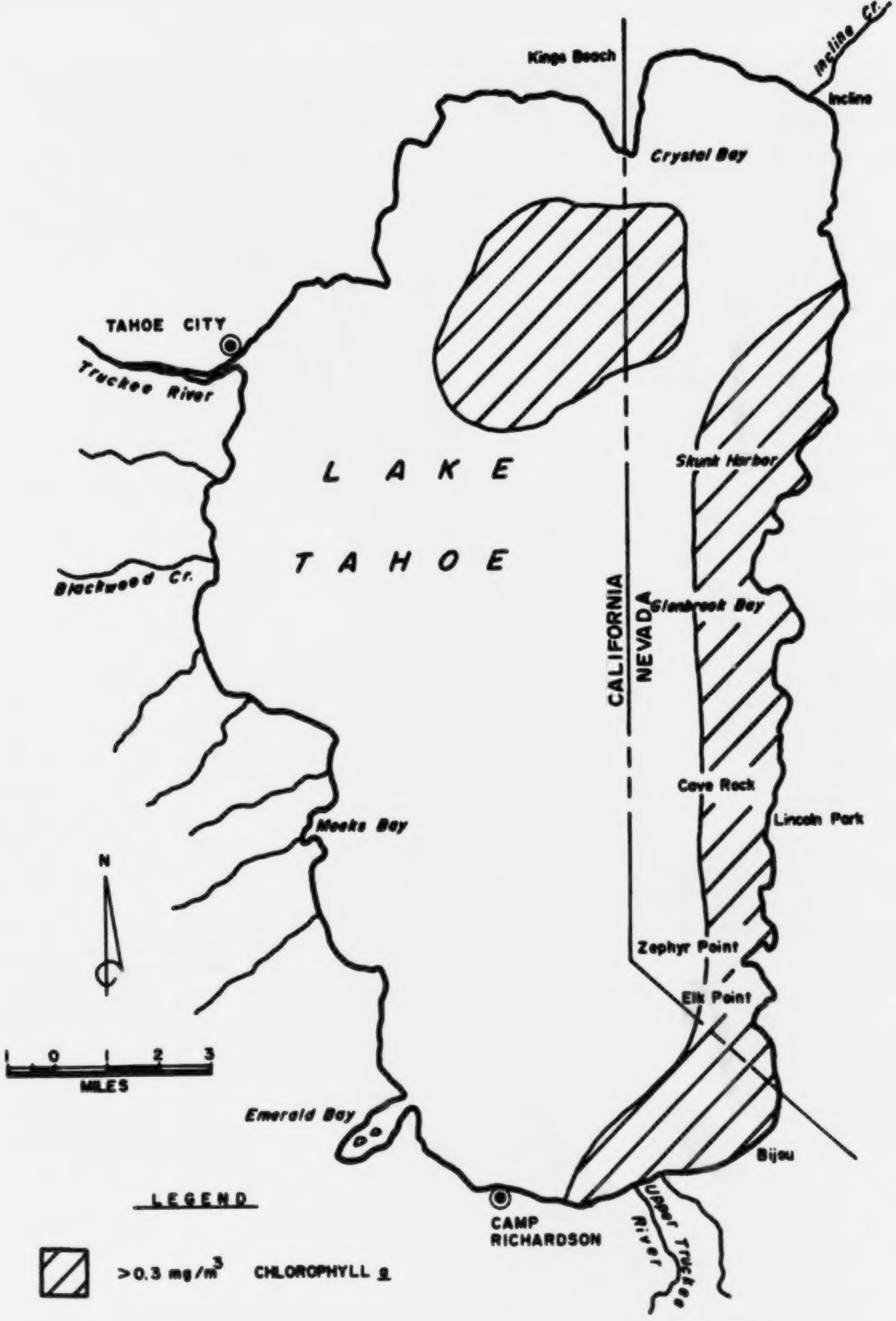
Kings Beach
Incline Cr.
Incline
Crystal Bay
TAHOE CITY
Truckee River
LAKE
TAHOE
Blackwood Cr.
CALIFORNIA
NEVADA
Skunk Harbor
Glenbrook Bay
Cave Rock
Lincoln Park
Meeks Bay
N
Zephyr Point
Elk Point
1 0 1 2 3
MILES
Emerald Bay
Bijou
LEGEND
CAMP RICHARDSON
Upper Truckee River
>0.3 mg/m³ CHLOROPHYLL a

Figure 58. Lake Tahoe chlorophyll *a* values.

cago Harbor, soluble phosphates (PO_4) averaged 0.04 mg/l and ranged as high as 0.15 mg/l. In Calumet Harbor, soluble phosphates averaged 0.05 mg/l and ranged as high as 0.14 mg/l; total inorganic nitrogen averaged 0.35 mg/l/N and ranged as high as 1.02 mg/l. Indiana Harbor water contained an average of 0.05-mg/l soluble phosphate and ranged as high as 0.12 mg/1. Total inorganic nitrogen averaged 1.56 mg/1 and

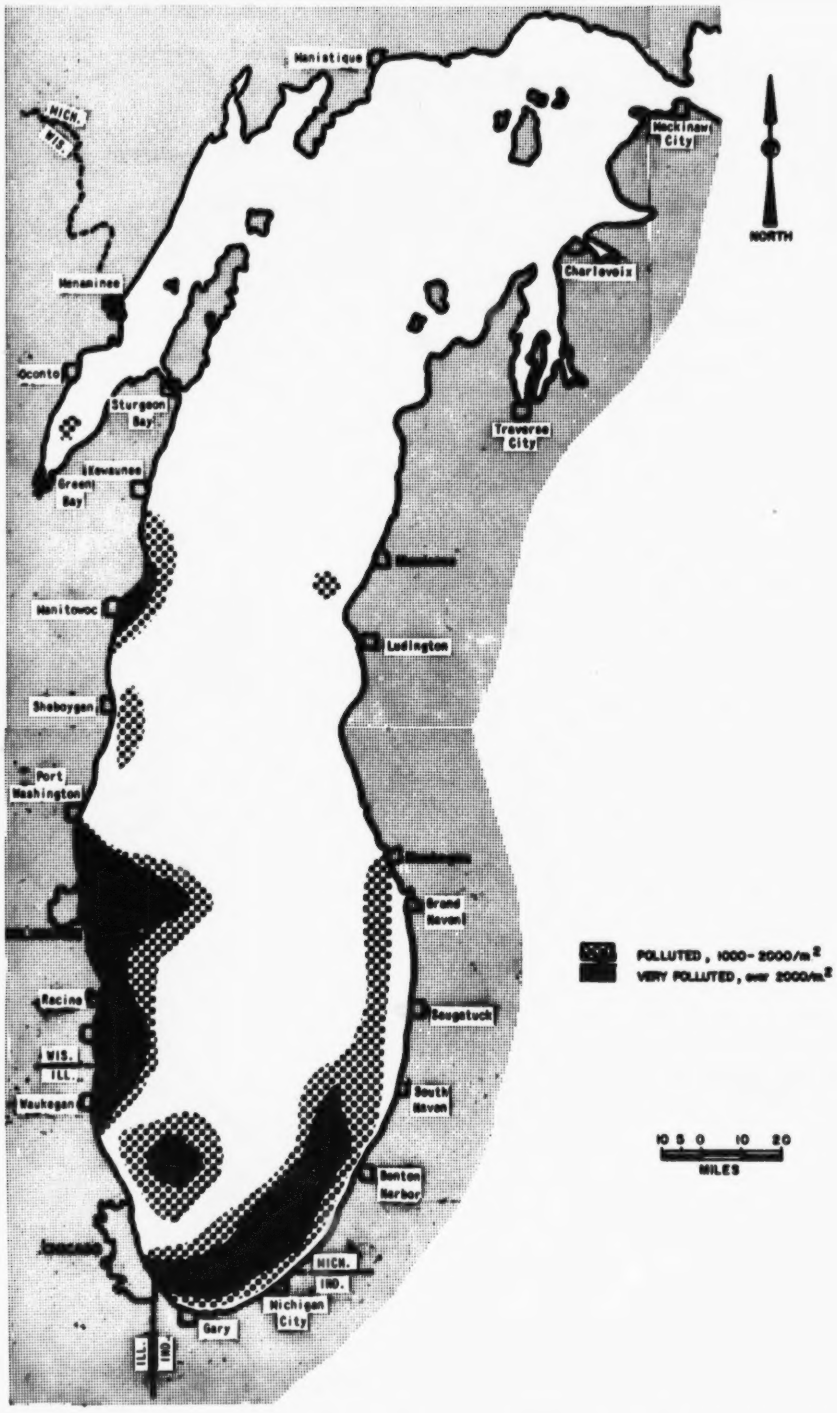
Manistique
MICH.
WIS.
Mackinaw City
NORTH
Menominee
Charlevoix
Oconto
Sturgeon Bay
Traverse City
Kewaunee
Green Bay
Manitowoc
Ludington
Sheboygan
Port Washington
Grand Haven
▨ POLLUTED, 1000-2000/m²
■ VERY POLLUTED, over 2000/m²
Racine
Saugatuck
WIS.
ILL.
South Haven
Waukegan
10 5 0 10 20
MILES
Benton Harbor
CHICAGO
MICH.
IND.
Michigan City
Gary
ILL.
IND.

Figure 59. Lake Michigan sludgeworm populations, number per square meter.

ranged as high as 3.14 mg/l. A concentration of 0.30 mg/l inorganic nitrogen is considered critical for stimulation of algal growth in the presence of adequate phosphorus.

Phytoplankton populations in the Chicago-Calumet area remained dense during the period of study. In 1962, up to 1,298 organisms per milliliter were found. In 1963, phytoplankton populations increased to 2,143 phytoplankton organisms per milliliter. Light penetration in the Indiana Harbor Canal was severely restricted; a Secchi disc was not visible at one meter.

The distribution of phytoplankton in Lake Michigan was generally influenced by wind-produced currents. In spring, 1962, over 500 phytoplankton per milliliter were collected from inshore waters, beginning at the Chicago-Calumet area and continuing north up the entire eastern lake shore (fig. 60). By the summer of 1962, the current pattern had changed; phytoplankton distribution became more random, except for high numbers of organisms (over 300 per ml) near Chicago and South Haven. Fall, 1962, phytoplankton counts again revealed high concentrations of over 500 organisms per milliliter along both the southeastern and southwestern shores.

Badfish Creek, Wisconsin

In the early history of Madison, Wis., Lake Monona received its raw sewage and later treated sewage effluent. In 1962, the Nine-Springs sewage-treatment plant was placed in operation and the effluent from this installation was carried via Nine-Springs Creek to the Yahara River upstream from Lakes Waubesa and Kegonsa. The enrichment of these lower Madison lakes by the highly nutritious effluent produced nuisance algal growths, offensive odors, and periodic fish kills. These conditions led to innumerable complaints, much debate, and evenutally legislative and legal action, which forced the diversion of effluent from the Madison Metropolitan Sewage District's Nine-Springs Treatment Plant around the lower Madison lakes.

The route chosen for the diversion of the Nine-Springs effluent necessitated five miles of 54-inch pipeline and nearly 4 miles of open ditch which led southward and entered Badfish Creek. Badfish Creek was straightened and improved to a width of at least 16 feet for 10 of its 14.5 miles of length. The unimproved portion after some meandering, enters the Yahara River downstream from the Madison lakes. Badfish Creek is a small stream that flows through typical oak opening agricultural lands in Dane and Rock Counties. Portions of the stream have had a history of being marginal trout water.

The Nine-Springs Sewage Treatment Plant provided primary and secondary treatment for all wastes from the Madison Metropolitan area of 85 square miles with a population of about 135,000. Flow through the plant averaged about 20 million gallons per day. Primary treatment consisted of screening, grit collection, and sedimentation. About one-fourth of the sewage received secondary treatment by the trickling filter process,

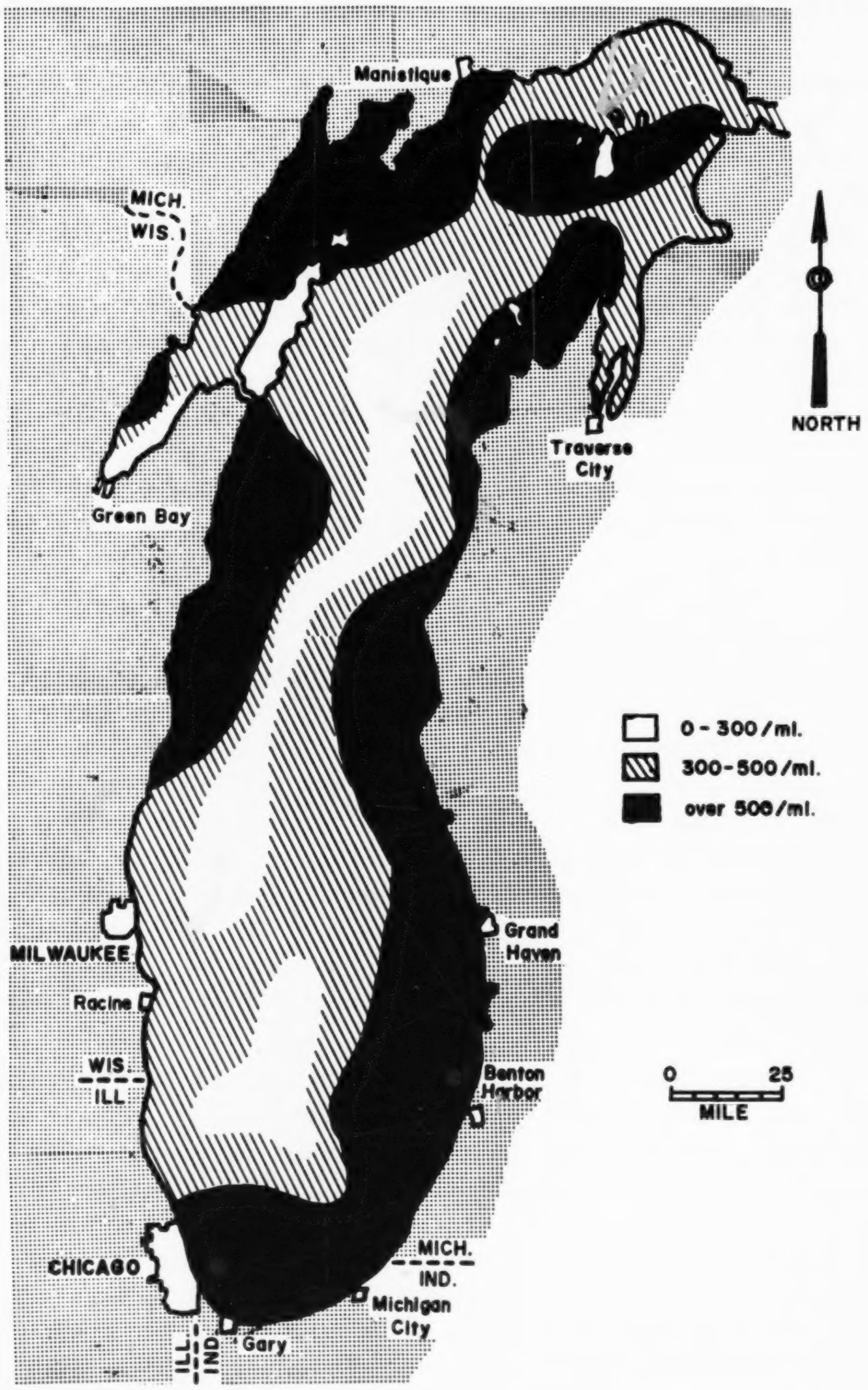
Manistique
MICH.
WIS.
Green Bay
Traverse City
NORTH
☐ 0-300/ml.
▨ 300-500/ml.
■ over 500/ml.
Grand Haven
MILWAUKEE
Racine
WIS.
ILL.
Benton Harbor
0
25
MILE
MICH.
IND.
CHICAGO
Michigan City
ILL.
IND.
Gary

Figure 60. Lake Michigan phytoplankton populations, number per milliliter, Spring, 1962.

and about three-fourths of the sewage received secondary treatment by the activated sludge process. The effluent received chlorination.

As the effluent left the 54″ pipeline, it entered a rather straight ditch with steep banks. The first approximately one-half mile of this ditch often carried a blanket of detergent foam. Approximately one mile farther downstream, the banks of the ditch became less steep, and as early as 1 year following diversion, there was evidence of vegetation encroachment, principally round-stemmed bulrush. Badfish Creek itself was dredged to a bottom width of 16 feet for approximately 4 miles, and a bottom width of 20 feet for the remaining 6 miles of improved stream. Along with the changes wrought by physical disturbance, there was a change in flow produced by the introduction of approximately 20 million gallons per day of effluent. Prior to diversion, Badfish Creek at about its midpoint between its origin and confluence with the Yahara River had an average flow of 9.6 c.f.s. for the 2½ years in which records were kept. Following diversion, the flow averaged 43 c.f.s.

Concurrent with the discharge of quantities of suspended solids, a sludge deposit built up over most of the upstream portions of Badfish Creek (Mackenthun et al., 1960). In some areas, especially in small pockets along the sides of the stream, this deposit approached 6 to 10 inches in depth. In most of the upstream region, as well as the ditch itself, the sludge was of sufficient thickness to produce a suitable habitat for a bountiful population of midge larvae.

Prior to and after diversion, organic nitrogen in Badfish Creek increased from 0.73 to 4.1 mg/l. Soluble phosphorus (P) rose from 0.19 to 5.96 mg/l. Following diversion the streams biochemical oxygen demand was 17.3 mg/l.

The mean phytoplankton volume showed no statistical difference either between stations on a given river or between the two periods of study for the same station. It thus appears that a sizable increase in nutrients in a flowing water situation had no substantial effect upon a volumetric production of phytoplankton.

Organisms that dwell upon and within the bottom deposits were studied at seven separate stations on four different dates in Badfish Creek.

Following diversion, the improved portion of Badfish Creek still maintained a coarse gravel bottom, and in the upstream reaches, the stream was choked with submerged vegetation. In the downstream reaches, this vegetation appeared to be less dense than before diversion. Long streamers of filamentous green algae (*Stigeoclonium* and *Rhizoclonium*), some of which were estimated to be 50 feet in length, were attached to bottom materials at numerous locations. In the upper areas of the stream, there was a green blanket of *Oscillatoria* covering the bottom. Sludge had deposited along the edges of the stream and covered portions of the vegetation. A definite sewage odor was present in upstream reaches in September, and this odor extended the full length of Badfish Creek in December, 1959. Much of the stream bed was covered with a slimy mat of the blue-green algae *Oscillatoria*, and especially in the December survey, much of the vegetation was covered with a prolific growth of a stalked protozoa belonging to the family *Epistylidae*. These formed a gray mass not unlike a dense growth of fungus.

The degradation of the stream following diversion is apparent when one examines the community of biological life living upon and within the bottom materials. Prior to diversion, between 10 and 14 different invertebrate species were recovered from each of the samples collected. Following diversion, the number of species was reduced to about five.

Prior to diversion, also, a balanced community of intolerant and tolerant organisms were observed. At nearly every station, caddisfly larvae (*Cheumatopsyche* and *Hydropsyche*), mayfly nymphs (*Baetis* and *Caenis*), and riffle beetle larvae were found in association with cranefly larvae, horsefly larvae, scuds, and miscellaneous midges. Very tolerant forms such as sludgeworms (*Tubificidae*) were also found, but occurred in very low numbers. In some locations, the intolerant caddisfly larvae formed most of the total population.

Following diversion, all stations in the ditch and in the improved portion of Badfish Creek supported a bottom-dwelling population comprised of sludgeworms (*Tubificidae*) and at least three species of very tolerant midge larvae (*Tendipes plumosus, T. tendipediformis,* and *T. decorus*). These were all considered to be very tolerant organisms and were found to be living in the sludge deposits on the bottom and along the sides of the stream. Near the lower end of Badfish Creek in the unimproved portion, tolerant and very tolerant bottom-dwelling organisms predominated. Occasionally, an intolerant form was observed, but this was only one among many of the more tolerant forms.

11

MARINE ENVIRONMENTS

San Diego Bay

SAN Diego Bay, a crescent shaped natural water body, has a length approximating 15 miles, a maximum width of 2½ miles and a surface area of about 18.5 square miles. Water depths vary from less than 1 foot in the southern end to 41 feet in the harbor entrance. The bay is surrounded by metropolitan San Diego with a population of over 860,000. The shoreline area, with the exception of a few small sections, has been developed for residential, recreational, military, or industrial uses. A deep-water harbor and extensive docking facilities permit use of the bay for naval activities, maritime commerce, industrial use, research, aesthetic enjoyment and recreation. Varied forms of practiced recreation include boating, fishing, swimming, water skiing, and wading.

There is no dilution of San Diego Bay by freshwater in summer and salinities range from 33 to 34 parts per thousand (p.p.t.) over the entire year except in the south end of the bay where evaporation may increase salinities to 35 or more p.p.t. Average water temperature varies from a high of about 26° C. during late summer to a low of 14–16° C. during winter.

Prior to 1963, municipal and industrial wastes from the metropolitan areas were discharged to the bay. Since the completion of an off-shore ocean outfall, wastes now entering the bay are minimal. The objective of the biological survey from October 8 to 28, 1967, was to assess the effects of pollution from ships and industries on San Diego Bay* biota.

San Diego Bay was divided into South Bay, Central Bay, and North Bay and 59 sampling stations were selected to depict aquatic life (fig. 61). A Petersen dredge was used to collect bottom-associated organisms. After a bottom sample was collected with the dredge, it was placed in a

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* San Diego Bay. An Evaluation of the Benthic Environment. L. P. Parrish and K. M. Mackenthun, Technical Advisory and Investigations Branch, Federal Water Pollution Control Administration, 5555 Ridge Avenue, Cincinnati, Ohio, 1968.

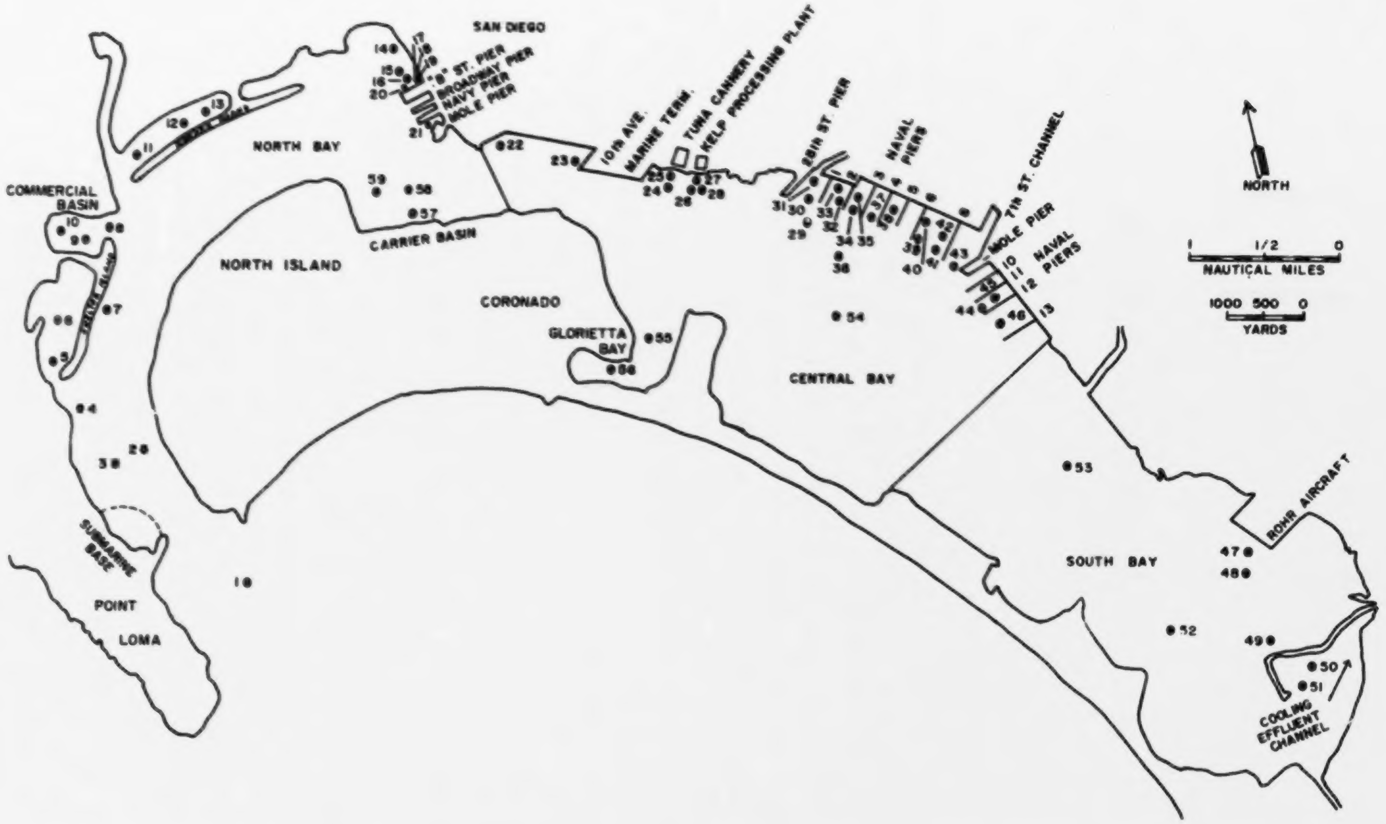
SAN DIEGO
"B" ST. PIER
BROADWAY PIER
NAVY PIER
MOLE PIER
10th AVE.
MARINE TERM.
TUNA CANNERY
KELP PROCESSING PLANT
28th ST PIER
NAVAL PIERS
7th ST. CHANNEL
MOLE PIER
NAVAL PIERS
NORTH
1 1/2 0
NAUTICAL MILES
1000 500 0
YARDS
COMMERCIAL BASIN
NORTH BAY
NORTH ISLAND
CARRIER BASIN
CORONADO
GLORIETTA BAY
CENTRAL BAY
SOUTH BAY
ROHR AIRCRAFT
COOLING EFFLUENT CHANNEL
SUBMARINE BASE
POINT LOMA
1
2
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Figure 61. Sampling stations on San Diego Bay, Calif., October 1967

small tub. Water was added and the sample was mixed to a slurry and strained through a U.S. Standard No. 30 sieve. The organisms and coarse debris were removed from the sieve and preserved for later examination.

To determine the extent and condition of sludge deposits, core samples were collected with a Phleger type coring device. Sludge depths were determined by measuring the length of penetration of the coring device, evident as a smear of sludge or mud on the outside of the tube, and the length of core collected. Core length was divided into the length of penetration to obtain a multiplication factor for the amount of compaction. This factor multiplied by the length of sludge-like material in the core equalled the assumed sludge depth.

South Bay was affected only slightly by pollution. In six of eight areas sampled, there were at least seven species of organisms and as many as 13 species in the sandy bottom at station 53. The most evident pollution was in the cooling effluent channel from a steam electric plant where the rocky bottom was covered with black sludge and filamentous algae (station 50). A water temperature of 88° F. was recorded here at the time of sampling. Floating mats of dead algae were evident and materials from the bottom had a distinct hydrogen sulfide odor. Polychaete worms numbered 1,400 per square foot, denoting a polluted area; only two kinds of other organisms were found in this channel, a pollution-tolerant snail being the more numerous. The channel contained 25 inches of organic sludge with 2.3 percent organic carbon and 0.16 percent nitrogen, indicative of organic debris. These sludges developed because of the rapid growth, die-off and deposition of plants and animals in the heated effluent.

In contrast, on the opposite side of a jetty separating the effluent channel from the bay (station 49), 188 polychaetes per square foot and seven kinds of adidtional organisms indicated a cooler and unpolluted environment. A gray mud and sand mixture contained 1.6 percent organic carbon and 0.16 percent organic nitrogen.

Central Bay was the most polluted. Near the center of the bay, station 54 indicated slight pollution only and supported 9 kinds of animals. Near San Diego's shore, many stations supported only polychaete worms and these ranged from 10 to 1,300 per square foot depending upon the degree of inhibitory toxins within the sludge. Severe organic pollution resulted in very low numbers of polychaetes with no other kinds of organisms. Other stations supported 1 to 3 organisms in numbers that seldom exceeded 6 per square foot in addition to the polychaete worms.

Sludge extended outward from shore to the area of the pierhead line. Within this area a gradation from active sludge inshore to a more stable sludge in the pierhead area was found. Sludge depth was determined to be 44 inches at one station and to exceed 30 inches at 9 of 16 station measurements in this area. Organic carbon varied from 2.2 to 9.9 percent and organic nitrogen from 0.14 to 0.91 percent. Comparing these data to those presented in table 7, much of the sludge was indicated to be fresh and actively decomposing.

North Bay had localized areas of pollution. Close to shore in the Carrier Basin, only polychaetes numbering 190 per square foot were found. Approximately 600 yards from shore, bottom materials had stabilized enough to support 40 polychaetes and 30 molluscs of one species per square foot. Over 30 inches of stable sludge with 2.0 to 2.2 percent organic carbon covered the moderately polluted bottom. Before 1963, the sewage outfall for the city of Coronado was located just east of the basin. Since the basin exceeds 40 feet in depth with little circulation, a sludge buildup resulted. Settleable solids discharged from carriers docked in the basin would also contribute to the sludge bed.

Across the bay, at the junction of B Street pier and the shoreline, a storm sewer outfall discharged organic wastes and other debris from the San Diego Zoo. Samples of the bottom within an approximately 40,000-square-foot area surrounding the outfall contained oil and black sludge that emitted hydrogen sulfide odors. The area supported 100 to 1,200 polychaetes per square foot and other pollution-tolerant organisms.

Inside Harbor Island (station 12), 6,500 polychaete worms per square foot were the only organisms found, in contrast to 90 worms per square foot and 8 kinds of organisms at station 13. Sand had been dredged from the area near station 12. A depression in the bottom had collected organic debris from the surrounding sand when it was redistributed, and provided an organically polluted substrate resulting from dredging.

Many polychaete worms, 3,400 per square foot, were found at the entrance to the Commercial Basin. Bottom materials were primarily sand. Halfway between the entrance and the end of the basin, a population of 2,000 polychaetes per square foot were found in a sand and clay mixture. Three-fourths of the distance into the basin, a soft, black-decayed sludge supported 200 polychaetes per square foot and three other kinds of organisms including pollution-tolerant snails and crabs. Suspended organic materials discharged from vessels docked in the area, and in water entering the bay, settled out of the slow moving water near the end of the basin. The large number of polychaete worms in the basin indicated moderate pollution.

Within North Bay, organic carbon within bottom sediments was not found to exceed 2.2 percent and organic nitrogen did not exceed 0.18 percent, which indicated generally stable sludges or organic silts and loam.

Analysis of all benthic data from San Diego Bay indicated that a finding of less than 5 kinds of organisms or more than 200 polychaete worms per square foot represented a polluted environment. Among all stations, the organisms per square foot varied from 13 to 6,400 and polychaetes made up 44 to 100 percent of the total numbers. Polychaete worms were found at all stations. Other organisms were found at 75 percent of the stations, and at 2 stations in South Bay the number of organism kinds reached 12 and 13.

Charleston Harbor, South Carolina

Samples of bottom-associated life, collected during September 20–24, 1965, revealed adverse conditions for benthos in several reaches of the Charleston Harbor estuary.*

In the lower reaches of the Ashley River (fig. 62), pollution was evident from the vicinity of Highway No. 7 downstream to the river's mouth. Midchannel benthic environments lacked bottom-associated organisms. Deposits in the channel near particular outfalls were comprised of dark-colored muds and oily substances that emitted odors similar to those of petroleum. Bioassays conducted with such deposits on certain snails, shrimps, and fish demonstrated that these muds were toxic to the organisms tested. Bottom deposits in downstream reaches to the mouth of the river consisted of black muds and organic matter, and produced foul odors like those of domestic sewage.

The lower reaches of the Cooper River contained significant discharges of wastes from upstream sources. Pollution was evident in the Cooper River in reaches immediately upstream and downstream from Buoy 60. Sludge deposits were abundant, and bottom associated organisms were not found. Marine worms were found in benthic environments both upstream and downstream from these grossly polluted reaches. Partial recovery was indicated near the mouth of the Cooper River where oysters and 7 other kinds of animals were found; however, certain clean-water associated forms such as shrimps and crabs were absent.

The Wando River was not discernibly polluted. Benthic reaches of this river were composed of hard clays mixed with scraps of shells and vegetation, and provided conditions suitable for 3 kinds of clean-water associated shrimp.

Moderately polluted areas were apparent in the main harbor from the mouths of the Ashley, Cooper, and Wando Rivers seaward to near Fort Sumter. Benthic environments in these reaches supported only marine worms. Bottom deposits were either black mud or black muds mixed with bits of shells, clay, or sand. Deposits consisting only of black mud were found in the reach south of Shutes Folly Island near the mouth of the Cooper River, and in the reach west of Shutes Folly Island; these muds emitted petroleum-like odors comparable to those associated with deposits in the lowermost reaches of the Ashley River.

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* A report on the water quality of Charleston Harbor and the effects thereon of the proposed Cooper River rediversion. Federal Water Pollution Control Administration, Southeast Water Laboratory, Charleston Harbor-Cooper River Project, Charleston, S.C. 1966.

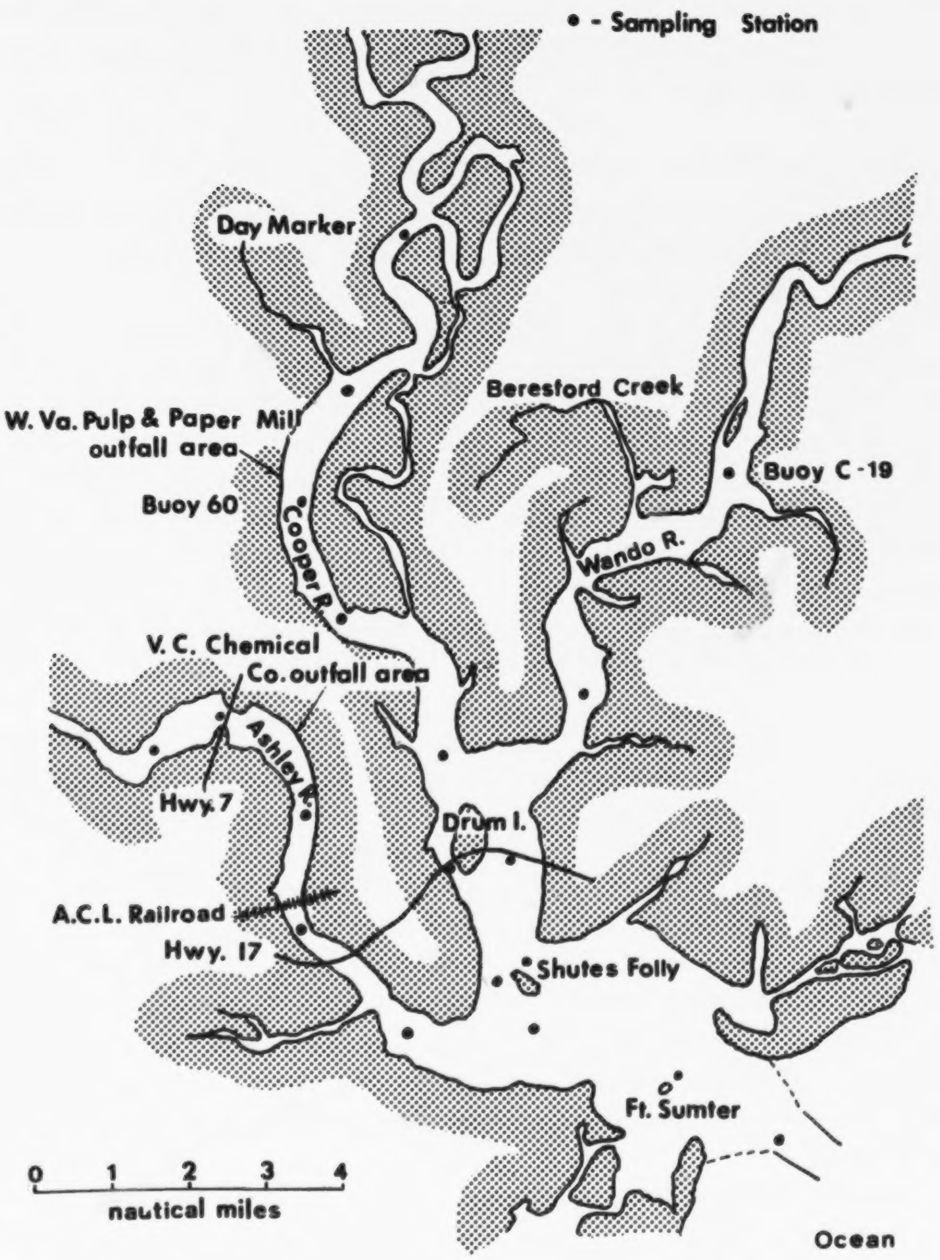
• - Sampling Station
Day Marker
W. Va. Pulp & Paper Mill
outfall area
Buoy 60
Cooper R.
Beresford Creek
Buoy C-19
Wando R.
V. C. Chemical
Co. outfall area
Ashley R.
Hwy. 7
Drum I.
A.C.L. Railroad
Hwy. 17
Shutes Folly
Ft. Sumter
0 1 2 3 4
nautical miles
Ocean

Figure 62. Biological sampling stations, Charleston Harbor 1965.

Benthic environments near Fort Sumter and seaward were not perceptibly polluted. Such environments were suitable for clean-water associated shrimp, and clams or crabs. Phytoplankton tended to be more abundant than 3.5 p.p.m. in reaches inland from Shutes Folly Island, and was less than 3.5-p.p.m. seaward from Shutes Folly Island. This distribution of phytoplankton was apparently associated with estuarine enrichment induced by waste discharges. Counts as numbers per ml. never exceeded 5,000.

Boston Harbor, Massachusetts

Boston Harbor, one of the most heavily used harbors on the Atlantic coast, is a major natural economic asset of Massachusetts. It is a watercourse that bridges the Atlantic Ocean to the Massachusetts coastline, serves both commercial and military navigation, provides berthage, protects from heavy seas, provides recreation, produces food, and assimilates untreated and partly treated sewage from 2.5 million people plus industrial wastes from the Boston metropolitan area. Wastes from an additional 0.4 million people and several industries are added to Boston Harbor or its tributaries from sources adjacent to the metropolitan area.

Boston Harbor has an area of approximately 44 square miles (28,000 acres), with depths ranging generally between 10 and 50 feet at mean low tide. Extensive areas of the bay are less than 15 feet deep. Large-craft navigation channels are dredged to maintain minimal depths of 30 feet, and small-craft channels are maintained at a minimum depth near 12 feet. Hydraulic and salinity features of the harbor are controlled chiefly by tides and, to a much lesser extent, by fresh water discharges from tributaries. The relatively small discharge of fresh water coupled with other hydraulic features precluded development of a salt-wedge water mass, and facilitated a vertically mixed type of estuary having more affinities with embayments than estuaries and aquatic life that was marine rather than estuarine.

Seven tributaries in addition to the Charles River drain into Boston Harbor. Only four, the Malden, Mystic, Charles, and Neponset Rivers, discharge significant amounts of fresh water. The Chelsea, Weymouth Back, Weymouth Fore, and Weir Rivers are tidal streams comprised mostly of saline harbor water. During periods of low precipitation, the tributary fresh water discharges to Boston Harbor were near 100 cubic feet per second (c.f.s.) and the discharge of sewage and industrial wastes exceeded 400 c.f.s. The total discharge of fresh waters during these periods did not drastically modify the salinity of the harbor. Except for mouths of tributaries, salinity values in all harbor reaches during periods of low precipitation were greater than 25 parts per thousand. Biological studies of Boston Harbor and its tributaries were conducted to assay water quality and its effect on aquatic life.*

The Charles River is the principal tributary to Boston Harbor. Numerous waste sources from combined sewers severely polluted this stream in reaches used intensively for recreation near its mouth. Only one kind of organism was found at mile 4.0, and none was found at mile 0.6 near the Longfellow Bridge. The paucity of organisms suggested that toxic conditions prevailed, thereby precluding establishment of bottom-associated animal life. Black oozy muds that emitted foul odors and contained oily residues were found here, and the surface of the river was pock-marked with bursting gas bubbles. The many combined sewers discharged highly carbonaceous and nitrogenous wastes. The organic carbon content of sludges near the river's mouth was 13.7 percent and organic nitrogen was 0.70 percent. The waters contained 940 μg/1 inorganic nitrogen (N), 270 μg/1 total phosphorus (P), and 180 μg/1 soluble phosphorus. Phytoplankton populations exceeded 10,000 cells per ml.

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* Biological Aspects of Water Quality Charles River and Boston Harbor, Mass. R. K. Stewart, Federal Water Pollution Control Administration, Technical Advisory and Investigations Branch, 5555 Ridge Avenue, Cincinnati, Ohio, 1968.

In addition to the Charles River, certain other tributaries contributed polluted water to Boston Harbor. The Mystic River at the Route 16 bridge near Medford, Mass. (fig. 63), supported only one kind of bottom animal. Substantial quantities of oily residues were observed in the black sludge that covered the river bottom. Additional qualitative sampling disclosed that black sludge deposits predominated in the benthic environment of the Mystic River to its confluence with the Malden River. Phytoplankton density in surface waters was high, exceeding 40 p.p.m., or 29,000 cells per milliliter.

The Malden River was severely polluted upstream from its confluence

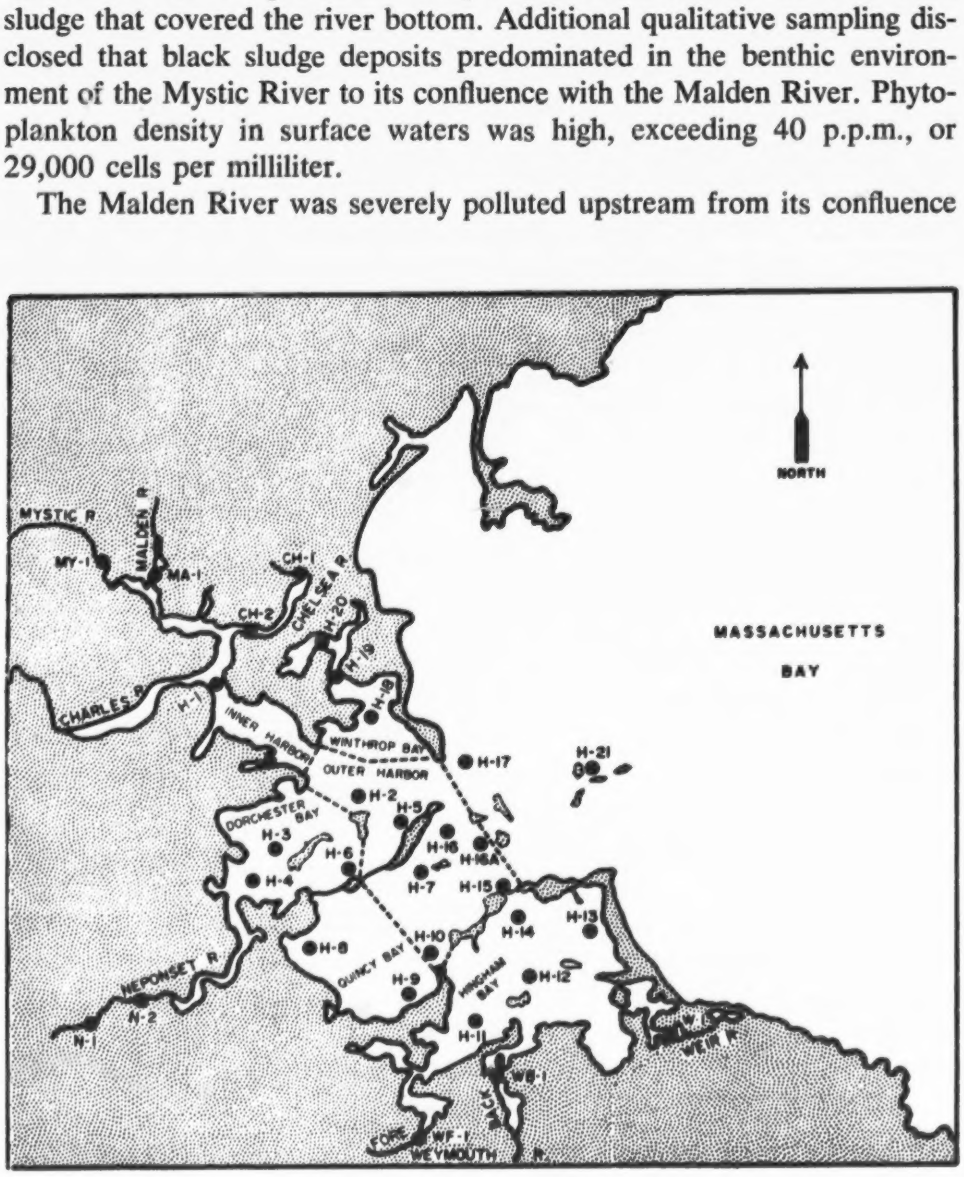
NORTH
MASSACHUSETTS BAY
MYSTIC R
MALDEN R
MY-1
MA-1
CH-1
CHELSEA R
CH-2
H-20
H-19
H-18
CHARLES R
H-1
INNER HARBOR
WINTHROP BAY
OUTER HARBOR
H-17
H-21
H-2
H-5
DORCHESTER BAY
H-3
H-6
H-16
H-16A
H-4
H-7
H-15
H-13
H-14
H-10
H-8
QUINCY BAY
NEPONSET R
H-9
HINGHAM BAY
H-12
N-2
N-1
H-11
W-1
WEIR R
WB-1
BACK
FORE
WF-1
WEYMOUTH
R

Figure 63. Station locations in Boston Harbor and tributaries.

with the Mystic River. Bottom-associated animals were not found, and 4 inches of black sludge mixed with oily residues covered the stream bottom. Surface waters contained more than 60,000 phytoplankton per milliliter that amounted to a density of 13.8 p.p.m. The Malden and Mystic Rivers contributed severely polluted waters to the inner reaches of Boston Harbor.

Marine waters supporting polychaete worms prevailed in all but one of the remaining tributaries and in all Boston Harbor reaches. Polychaete worms were sufficiently common in these waters that their abundance was used to show areas and degrees of over-enrichment. The use of marine worms for these purposes is not unlike the use of sludgeworms to delineate areas of over-enrichment in fresh waters because the nutritional and substrate requirements of both groups of organisms are similar. Polychaete worm populations that exceeded a density of 200 per square foot in the marine waters of Boston Harbor were considered indicative of excessive enrichment (fig. 64).

The confluence of the Chelsea, Mystic, and Charles Rivers forms Bos-

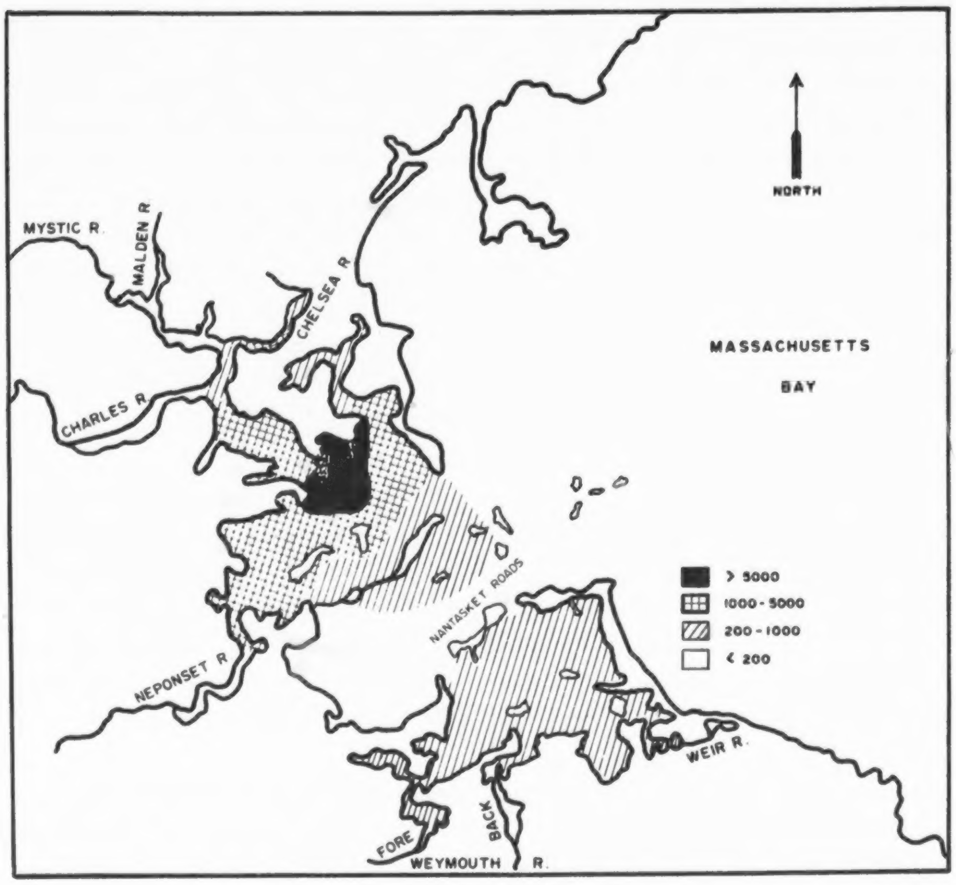
NORTH
MYSTIC R.
MALDEN R.
CHELSEA R.
CHARLES R.
MASSACHUSETTS BAY
NANTASKET ROADS
NEPONSET R.
WEIR R.
FORE
BACK
WEYMOUTH R.
■ > 5000
▦ 1000-5000
▨ 200-1000
☐ < 200

Figure 64. Number of polychaete worms per square foot, Boston Harbor and tributaries, July–August 1967.

ton Inner Harbor. Tidal currents in Boston Inner Harbor are strong and would displace rapidly the wastes entering the area from these tributaries, but additional wastes entering the Inner Harbor exceed the waste dispersal capacity of the currents. Consequently, some wastes from local and tributary sources are deposited here as sludge. Qualitative samples taken in the vicinity of the confluence of these tributaries showed that oily sludges covered these bottom reaches of the Inner Harbor, and that the predominant associated aquatic life were polychaete worms. Settleable solids from additional waste sources were deposited in the seaward reach of Boston Outer Harbor north of Spectacle Island where they formed sludge deposits that supported more than 5,000 polychaete worms per square foot.

Clean water, as indicated by a great variety of benthic organisms, was found seaward from Boston Harbor in Massachusetts Bay between Green Island and the Brewester Islands. Qualitative samples from this area showed that it supported at least 14 different groups of organisms. Many of these were clean-water-associated animals such as chitons, sponges, starfish, shrimp, brittle-stars, and crabs. Sludge-like deposits were not present here, and bottom materials were comprised of clay, clean sand, rocks, and rubble that also supported a variety of attached brown, green, and red algae.

Sewage waste waters discharged through the many outfalls in Boston Harbor and associated bays and tributaries caused very high concentrations of ammonia nitrogen (N) and soluble phosphorus (P) that averaged or exceeded 100 and 40 micrograms per liter, respectively in 390 samples from all reaches of the harbor inland from Massachusetts Bay. The highest average concentrations of such nutrients in 22 samples occurred in Boston Inner Harbor at station H–1, where ammonia nitrogen was 200 micrograms per liter and soluble phosphorus was 70 micrograms per liter. Maximum single sample concentrations were 300 micrograms per liter ammonia nitrogen (N) and 120 micrograms per liter soluble phosphorus (P) at station H–1.

High concentration of inorganic nutrients in these and certain associated waters caused excessively dense populations of phytoplankton that averaged more than 1,000 per milliliter in about 35 square miles or 66 percent of Boston Harbor, including the Weymouth Back and Fore Rivers, and the saline reaches of the Chelsea, Charles, Malden, and Mystic Rivers (fig. 65). Studies in other marine and estuarine waters indicate that phytoplankton populations more dense than 1,000 per milliliter are indicative of over-enrichment in such waters.

In addition to causing excessive phytoplankton populations, the nutrients stimulated dense growths of attached marine plants. Observations throughout Boston Harbor disclosed such growths on most buoy, pier, and marina facilities. Several intertidal and shallow areas of the harbor and certain reaches of Winthrop Bay also supported dense growths of at-

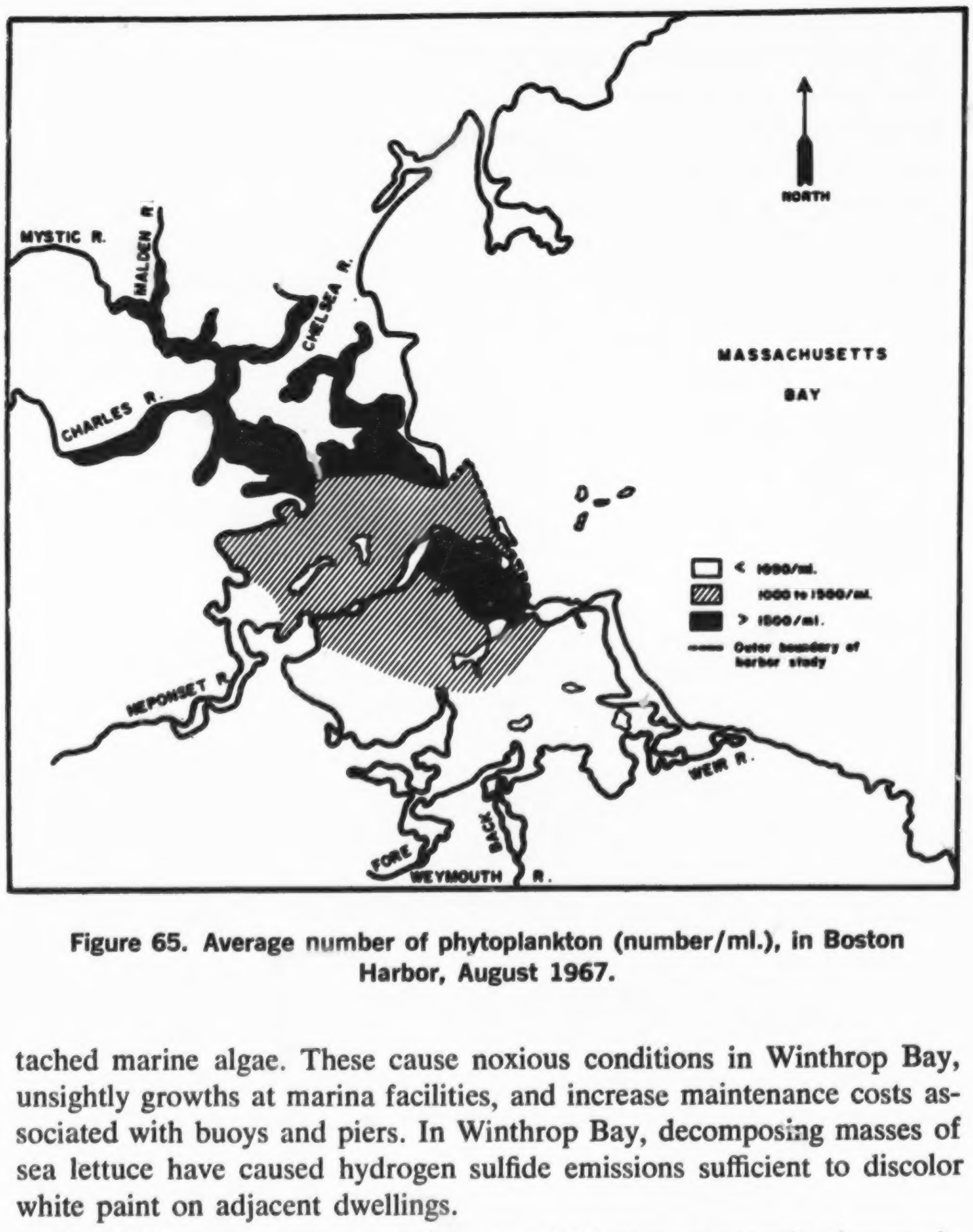
NORTH
MYSTIC R.
MALDEN R.
CHELSEA R.
CHARLES R.
MASSACHUSETTS
BAY
< 1000/ml.
1000 to 1500/ml.
> 1500/ml.
Outer boundary of harbor study
NEPONSET R.
WEIR R.
BACK
FORE
WEYMOUTH R.

Figure 65. Average number of phytoplankton (number/ml.), in Boston Harbor, August 1967.

tached marine algae. These cause noxious conditions in Winthrop Bay, unsightly growths at marina facilities, and increase maintenance costs associated with buoys and piers. In Winthrop Bay, decomposing masses of sea lettuce have caused hydrogen sulfide emissions sufficient to discolor white paint on adjacent dwellings.

The 12.5 percent organic carbon and 0.34 percent organic nitrogen in sludge of saline tributaries were found in the most inland reach of the Chelsea River near the Broadway Street bridge; these values are indicative of actively decomposing organic solids. Sludges from the bayward reach of the Chelsea River, and from the Malden, Mystic, and Neponset Rivers had more than 4-percent organic carbon, and more than 0.10 percent organic nitrogen. Such values are suggestive of excessively enriched deposits.

The highest percentages of organic carbon (23.5) and organic nitrogen (1.29) associated with harbor sludges were found in the Fort Point Channel. This reach was very intensively polluted, and septic. Such values are not unlike those associated with raw wastes from packinghouses, sewage, or rapidly decomposing sludge (table 7).

In addition to surface deposits, core samples from several harbor stations were analyzed. Those from stations somewhat distant from immediate waste sources and known channel dredging activities had decreasing percentages of organic carbon ranging from 4.7 at the top of the core to 0.3 at the bottom, and organic nitrogen ranging from 0.48 to 0.03, suggestive of gradual increases in percentage of organic matter with time and deposition.

12

WATER TREATMENT

ORGANISMS that may cause, or have been known to cause, trouble in water supplies include several species of algae, protozoa, and diatoms that produce tastes and odors and clog filters, iron bacteria that produce nauseous tastes and odors and clog pipes, copepods whose eggs pass through filters, very small nematode worms, sowbugs in the distribution system, midge larvae or bloodworms, and snails and molluscs.

There may be present in surface waters, various types of organisms both plant and animal, which vary in complexity and size. They are uncommon or absent in groundwater supplies unless stored in uncovered reservoirs, but are common and widespread in surface waters. Perhaps none of the organisms found in surface waters that may be used for domestic purposes is injurious to health. The chief complaints against them are interferences with filtration or other water treatment, and their effects upon the palatability and aesthetics of the water. Organisms may accumulate in such numbers that waters become unsightly and turbid, and many organisms impart disagreeable odors and colors to the water.

The need for aquatic biologists to participate in water works engineering was well stated by Lackey (1950) when he concluded that before a source for a water supply is finally selected it should be surveyed by a competent aquatic biologist to evaluate present and probable future biological conditions that might affect water quality. Reservoirs and storage facility plans should be reviewed by him to determine possible biotic changes that may occur. The elimination of undesirable shallow areas can often be accomplished more cheaply during construction than maintaining these areas after reservoir filling. In areas where growths of algae and other aquatic plants present an annual problem, a study by a qualified aquatic biologist may indicate causes for such growths and methods of control.

Reservoir Bed Preparation

Impounding water may result in the leaching of undesirable materials from flooded soils. When present in excessive concentrations, several materials can interfere with desired water uses:

1. (1) Color is important in water supply sources because it is objectionable aesthetically. The maximum recommended limit in ***Water Quality Criteria*** (Anon. 1968) is 75 units in raw water, and less than 10 units in finished water are desirable. Complaints from consumers occur at 15 units and increase with additional color. The measurement of color is based on an empirical scale that is affected by the true color of the water, as well as the material suspended in the water.
2. (2) Iron in water supplies should not exceed 0.3 mg./l, and its absence in finished water is desirable. In excess, it stains laundry, produces a disagreeable taste, interferes with filtration, and supports iron bacterial growths within a water system. The amount of iron present in water is dependent upon other chemical characteristics of the water:
    - (a) It is more soluble when oxygen is absent.
    - (b) It is more soluble in acidic waters.
    - (c) Organic materials increase its solubility.
3. (3) Manganese should not exceed 0.05 mg./l in raw water and should be absent from finished water because of stains imparted to laundry, and objectionable tastes. Factors that affect its quantity in water are similar to those for iron.
4. (4) Phosphorus concentrations in excess of 0.1 mg/l may interfere with coagulation in water treatment plants and, in excess of 0.05 mg/l in water supplies, may stimulate the excessive growth of algae and other aquatic plants. Excessive growths impart undesirable tastes and odors to water, interfere with water treatment, become aesthetically unpleasing, interfere with recreation and aquatic life, and alter the chemistry of waterways.
5. (5) The chemical state of nitrogen is dependent on the overall limnology of the waterway. The decomposition of organic materials produces ammonia that, in an environment without abundant oxygen, may not be oxidized to nitrate; ammonia reacts with chlorine to form chloramines, which interfere with disinfection. In addition, nitrogen is a nutrient that supports excessive aquatic vegetation that can interfere with water uses.

Sylvester (1965) studied a new impounding reservoir on the Green River, Washington, where part of the inundated land had been heavily forested, with a large swamp in the central impoundment area. The effect of reservoir soil on the quality of the overlying water was studied during the first two years of impoundment by analyzing samples of water from the influent and effluent and from the reservoir 1 foot above the bottom in selected areas. Examination of samples of soil, soil cores, and typical forest debris indicated that the leaching and decomposition of organic constituents in the soil may have profound adverse effects on the quality of the water, particularly color, odor, corrosivity, and concentration of dissolved oxygen, and may provide nutrients which support heavy growths of algae. Organic substances in the latter stages of decay (humus) have less effect than those in the early stages of decay. To prevent severe degradation of water quality in new reservoirs, much of the woody debris should be removed, particularly rotting logs and rotting stumps, and if tests show that organic soils could have a marked effect over a significant area of the reservoir, these soils should be excavated or covered with at least 1 foot of mineral soil, which is effective in preventing adverse effects on the overlying water. As a reservoir ages, the effects of the original soil on the overlying water will diminish because of a decrease in the rate of decay and the extraction of available solutes; and incoming silt and plankton will gradually cover the original soils.

When new reservoir areas are flooded, vegetation is killed, there is decomposition and leaching of the topsoil, and the release of nutritive materials provides a desirable environment for algae and other microscopic organisms. Allen (1960) found that the rate of decomposition for organic materials in an impoundment requires 10 to 15 years for stabilization, with approximately 14-percent improvement annually. By carefully carrying out a proper reservoir site preparation, he reasoned that odor problems could be avoided.

Hammerton (1959) discusses soil stripping during reservoir construction as a preventative of later biological problems. Sylvester and Seabloom (1965) also discuss the merits of soil stripping. They conclude that a site for an impounding water reservoir must be selected with care because of the potential effects on water quality. The site characteristic most responsible for undesirable effects was found to be the organic content of the soil. Its undesirable effects depended on time, temperature, and light. Undesirable effects were proportional to the amount of organic matter in the soil and were inversely proportioned to the age or state of decay of the organic materials.

Tastes and Odors

From a nationwide survey reported in 1957 (Sigworth, 1957), it was indicated that algae were considered by 241 waterworks officials to be the most frequent causes of tastes and odors in water supplies, with other types of decaying vegetation second in importance. Decay or decomposition is brought about by fungi and bacteria, including the actinomycetes. Often a considerable proportion of the decaying vegetation is composed of dead algal cells. The odors that are produced through the activities of fungi and bacteria may be either from the intermediate products formed during the decomposition or from special substances that are synthesized within the cells of the microorganisms. The latter appears to be true in the case of actinomycetales. Algae were listed as the causative agent in 82 percent of the reports, decaying vegetation in 67 percent, industrial wastes in 38 percent, and other causes in 23 percent.

A few algae are well know for the production of specific distinctive tastes and odors, while a larger number of others are associated with tastes and odors that vary in type according to local conditions. Often certain diatoms, blue-green algae, and pigmented flagellates are the principal offenders but green algae may also be involved. Thirty-nine species have been selected by Palmer (1959) as representative of the more important taste and odor algae. They are listed alphabetically under their respective groups in table 13. Other genera and species, in addition to the ones selected, must be considered also as potential offenders.

Silvey (1963) noted a relationship between summer blooms of blue-green algae and rapid growths of actinomycetes three to four weeks later Most concentrated tastes and odors appear as associated with the latter. Silvey and Roach (1964) state that ". . . it has been observed for many years in the literature that the degradation of algal remains may result in a multitude of types and intensities of odors and tastes in the water supply. Some odors are contributed directly by the algal degradation products dissolved in the water, whereas others are merely described as decaying vegetation." Disintegrating algae are associated with increases in gram-negative heterotrophic bacterial populations, following which there is generally a new growth of algae, either diatoms or blue-green algae. When blue-green algae predominate and algal mats form on the surface or in protected water areas, actinomycetes attack the remains of the algae thus reducing the gram-negative heterotrophic bacteria. Various odors, depending upon the predominant organism, its degradation products or metabolites, are released. Silvey and Roach (1964) point out that when a stream or reservoir is highly polluted, one cycle may impinge upon another to the extent that total confusion results if attempts are made to determine what stage of the microbiotic cycle is operating in a particular water supply at a specific time.

Symons (1956) states that 500 to 1,000 areal standard units of odor-producing organisms are generally conceded to cause trouble in water supplies but the range varies widely for different organisms. The Metropolitan Water Commission of Boston was quoted by Symons as setting maximum allowable limits of troublesome algae before control treatment was instigated. For some genera (e.g. *Chlamydomonas*) the level was as low as 10 standard units per ml. For other flagellates such as *Cryptomonas, Synura,* and *Uroglenopsis* it was 200; for the blue-green alga, *Aphanizomenon*, the level was 1,000 areal standard units per ml.

Menasha, Wisconsin draws its water from Lake Winnebago, an algal-laden surface supply. Taste and odor problems were severe in 1939 based upon Marx's (1951) statement, ". . . as an example of how bad the water can get, during August of 1939 the water temperature was 85, the algae count reached 50,000 units per ml., turbidity was 200 p.p.m. and

Table 13. Odors, tastes, and tongue sensations associated with algae in water

	Odor when algae are—			
Algal genus	Moderate	Abundant	Taste	Tongue sensation
Actinastrum		Grassy,musty		
Anabaena	Grassy, nasturtium, musty.	Septic.		
Anabaenopsis.		Grassy		
Anacystis	Grassy	Septic.	Sweet	
Aphanizomenon	Grassy, nasturtium, musty.	Septic.	Sweet	Dry.
Asterionella	Geranium, spicy	Fishy.		
Ceratium.	Fishy.	Septic.	Bitter	
Chara	Skunk, garlic.	Spoiled, garlic.		
Chlamydomonas	Musty, grassy.	Fishy, septic	Sweet	Slick.
Chlorella		Musty.		
Chrysosphaerella.		Fishy.		
Cladophora		Septic.		
(Clathrocystis)				
Closterium		Grassy		
(Coelosphaerium)				
Cosmarium		Grassy		
Cryptomonas	Violet	Violet	Sweet	
Cyclotella	Geranium	Fishy.		
Cylindrospermum	Grassy	Septic.		
Diatoma		Aromatic		
Dictyosphaerium	Grassy, nasturtium	Fishy.		
Dinobryon	Violet	Fishy.		Slick.
Eudorina		Fishy.		
Euglena		Fishy.	Sweet	
Fragilaria	Geranium	Musty.		
Glenodinium		Fishy.		Slick.
(Gloeocapsa).				
Gloeocystis		Septic.		
Gloetrichia		Grassy		
Gomphosphaeria.	Grassy	Grassy	Sweet	
Gonium		Fishy.		
Hydrodictyon		Septic.		
Mallomonas	Violet	Fishy.		
Melosira	Geranium	Musty.		Slick.
Meridion		Spicy		
(Microcystis)				
Nitella	Grassy	Grassy, septic.	Bitter	
Nostoc	Musty	Septic.		
Oscillatoria	Grassy	Musty, spicy		
Pandorina		Fishy.		
Pediastrum		Grassy		
Peridinium	Cucumber	Fishy.		
Pleurosigma		Fishy.		
Rivularia	Grassy	Musty.		
Scenedesmus.		Grassy		
Spirogyra		Grassy		
Staurastrum		Grassy		
Stephanodiscus.	Geranium	Fishy.		Slick.
Synedra	Grassy	Musty.		Slick.
Synura	Cucumber, muskmelon, spicy.	Fishy.	Bitter	Dry, metallic, slick.
Tabellaria	Geranium	Fishy.		
Tribonema		Fishy.		
(Uroglena)				
Uroglenopsis.	Cucumber	Fishy.		Slick.
Ulothrix		Grassy		
Volvox	Fishy	Fishy.		

the odor reached 300. A treatment of over 100 p.p.m. of carbon and 9 grains of alum, cut the odor down to about 15 and the turbidity down to about 10, in the finished water. This water was obviously not satisfactory for use, but nothing could be done about it." In 1946, a 25-million gallon pretreatment basin, giving a detention period of 7 or 8 days, with concrete baffles to ". . . force the water from one shore of the basin to the other five times as it travels from the inlet to the outlet" was placed in operation. As the water flows into the basin it is given a dosage of 2 mg/l of copper sulfate throughout the algal season regardless of type of algae, pumpage, or any other variable (Marx, 1951). By the time the water reaches the water treatment plant inlet, the algae have been killed, they have decomposed, the odors have been reduced an average of 67 percent and just a very fine turbidity is left. In five years of use, less than an inch of material settled on the bottom of the basin, according to Marx.

Oshkosh, Wis., gets its water from Lake Winnebago. Conditions in the lake are ideal for prolific algal growths, reducing filter runs to as low as 60 minutes, which results in a great reduction in plant output and causes water shortages during the summertime (Hartman, 1961). In view of the fact that the city of Menasha, Wis., which also uses Lake Winnebago as its source of water supply, had operated a pretreatment basin for several years, it was concluded that pretreatment of this water with copper sulfate should be considered. Treatment of the water with 2 parts per million of copper sulfate followed by a 7 day retention period under maximum conditions was determined to be the proper pretreatment. A presettling basin was constructed in a bay by enclosing an area of approximately 30 acres with an earthen dyke. This basin was baffled to prevent short circuiting. The pretreatment provided has reduced the amount of water required for backwashing from as much as 9.8 percent of the plant capacity in July and August to 2.5 percent for the same 2 months. The number of filter backwashes per day was reduced from 18.6 in 1959 to 3.8 in 1960, and the water used for backwashing was reduced from an average of 8 percent in 1959 to 2.6 percent in 1960. Pretreatment has reduced the cost of chemicals by almost 31 percent and the backwash water by 67 percent while at the same time a better quality water was produced.

Rohlich and Sarles (1949) discussed the products of bacterial decomposition of algae and their responsibility for odors and tastes in water. They assumed that the proteins of algae permitted a full complement of amino acids for bacterial action, and listed some 30 known odoriferous compounds produced. Jenkins et al. (1967), using gas chromatographic techniques, identified several odorous organic sulfur-containing compounds from cultures of blue-green algae. The cultures were bacterially contaminated and the odorous sulfur compounds most probably resulted from bacterial putrefaction of the blue-green algal cells. Odorous sulfur compounds included methyl mercaptan, dimethyl sulfide, isobutyl mercaptan, and n-butyl mercaptan. A compound produced by certain actinomycete cultures, responsible for a persistent musty odor, was isolated in high purity and identified by chemical and spectroscopic properties (Dougherty et al., 1966).

Dickson (1968) discussed the control of actinomycetic odors. He noted that actinomycetes growing on the remains of blue-green algae produce the most intense odors and luxuriant growths. Listing 3 "fairly successful" control techniques, he suggests algicides to control growths of blue-green algae, activated carbon to absorb taste and odor compounds and other organic substances, and the use of *Bacillus cereus* in concentrations of 1.2 x 10^5 to reduce rapidly the tastes and odors produced by actinomycetes. The latter technique was successful at the Lake Hefner treatment plant, Oklahoma City, when the bacteria were cultured in 5,000-gallon tanks for 24 to 36 hours and introduced into the reservoir or pretreatment basin as either a preventative or control measure.

Filter Clogging Problems

As water passes through a sand filter in the water treatment plant the spaces between the grains of sand become filled with colloidal and solid particles that have been dispersed in the water. When the raw water comes from a surface supply such as a reservoir, lake, or stream, the algae that are invariably present will be well represented in the material collected by the sand filter. They are frequently the primary causes of filter clogging.

Efficient coagulation and sedimentation may remove 90 to 95 percent of the algae from the water. The algae remaining in the water may still be sufficient to cause gradual or even rapid loss of head in the sand filter. The clogged filter must then be backwashed. Filter runs may often extend for 30 to 100 hours before backwashing is required, or may be shortened to less than 10 hours when algae are present (Tarlton, 1949). In Chicago, when the water to be filtered contained approximately 700 microorganisms per ml., principally two diatoms *Tabellaria* and *Fragilaria,* the filter runs were 4.5 hours. Three days later, when the count was down to approximately 100 per ml., the filter run increased to 41 hours (Baylis, 1955). In Washington, D.C., filter runs were reduced from an average of 50 hours to less than 1 hour because of a sudden influx of the diatom *Synedra,* which occurred in the raw water and reached 4,800 cells per ml (Lauter, 1937).

Most of the microscopic organisms present in water that is passing through a rapid sand filter generally will be caught in the top one-half inch of the sand. This is particularly the case when the organisms are abundant in the water. A few of the organisms will penetrate deeper into the filter bed while others disintegrate quickly as they come in contact with the sand. The longer the filter run the greater the percentage of organisms that will penetrate below the top one-half inch.

In Chicago, a study was made of the number of certain diatoms that were caught on the surface of rapid sand filters. The samples were collected immediately before the filters were backwashed. During 1 year of this study, *Tabellaria* ranged in numbers from 496,000 to 936,000 per square inch of filter surface in April, and from 1,824,000 to 8,016,000 in November. In contrast, the range for *Melosira* was from 784,000 to 2,624,000 in April, and only 16,000 to 416,000 in November (Baylis, 1957).

Gamet and Rademacher (1960) found in a study of filter runs with Lake Michigan water that 37 percent of the runs for all test filters in 12 filtration plants were less than 20 hours. A filter run of 20 hours was taken as the economic breakpoint time. Loss in revenue for the 12 plants was estimated at $226,000 for the 9-month period. *Tabellaria* was the most important of the Lake Michigan plankton that exhibited filter-clogging tendencies. In a followup study, Poston and Gamet (1964) reported that excessive filter clogging at Cleveland was prevented by use of slightly higher chlorine and alum doses; at Toledo, Ohio, short filter runs were remedied by treatment with excess lime, with the lime floc carrying most of the diatoms down in the sedimentation basin and by lengthening the filter runs from 3 to 24 hours; at Detroit, Mich., shortened filter runs during winter and early spring have lasted as long as a month and alum costs in excess of that required for turbidity were as high as $15,000 per month. They reported that *Tabellaria* was beyond doubt the plankton genera causing the most serious problem with filter runs with Lake Michigan waters although *Asterionella, Melosira, Synedra* in combination also reduced filter runs, and *Cyclotella, Stephanodiscus, Oscillatoria, Fragilaria* and *Tribonema* were reported to cause filter clogging.

DeCosta and Laverty (1964) reported that filter washes cost the East Bay Municipal Utility District of Oakland, Calif., about one dollar apiece.

Microstraining

Microstraining has been succesfully used to alleviate organism problems in water supplies. At Kenosha, Wis., microstraining equipment was installed at the water plant at an initial cost of $330,000 primarily to reduce microorganisms prior to filtration (Nelson, 1965). The output of finished water from this plant has been increased by up to 25 percent, thereby providing 5 m.g.d. of extra water for sale to the public during peak demand periods which otherwise would have been used to backwash filters. Algal removals by microstraining have ranged from 46 to 97 percent.

On 29 sampling dates extending from July 22 through September 6, 1961, water pumping rates at Kenosha varied from 10 to 27 m.g.d. and from 1½ to 10 hours of sustained pumping.* The efficiency of the microstrainer depends on the number, size, and shape of the algal cell,and whether or not the cells occur singly or in chains. Rate of pumpage did not appear to affect efficiency in this study. The microstrainer was very efficient in removing those algal cells occurring in chains, since the water following the strainers contained only single cells or chains of 2 or 3 cells in length. The algal mass was reduced from 141±10 to 11±3 pounds per day (wet weight) in passing through the microstrainers for an overall volumetric efficiency of 91.9 percent. The number of individual algal cells was reduced from 47±11 trillion per day to 5±1 trillion in passing through the microstrainers for an average reduction of 88.8 percent. The efficiency of the microstrainer varies from one species of alga to another. For example, there was little reduction in *Stephanodiscus* spp. with the passage of water through the microstrainer, because the species occurring in these waters were small enough to pass with ease through the 35-micron mesh of the microstrainer.

In testing a pilot microstrainer of 35-micron aperture on Lake Winnebago, Wis., raw water in 1957, it was found that the poorest reduction performance by the fabric was experienced on the dates when the plankton counts were the highest. Blooms of *Anabaena* and *Microcystis* were occurring. Five algal genera consistently passed through the microstraining fabric. These were the blue-greens *Anabaena* and *Aphanizomenon,* the diatoms *Cyclotella* and *Navicula,* and the green flagellate, *Phacotus.* On July 25, 1957, the algal count on the intake water to the microstrainer was 10,030 organisms per ml and the reduction through the microstrainer was 41 percent; on August 21, the raw water count was 47,270 organisms per ml. and the reduction was 25 percent; on August 22 with a raw water count of 30,350 the reduction was 16 percent (26,600 *Anabaena* spp, per ml); and on August 28, the reduction was 37 percent with 4,740 organisms per ml. in the intake water.

Berry (1961) stated that during the 15 years that microstrainers have been used at Belleville, Ontario, they have proven their value under prescribed conditions. They are effective in the removal of algae. Care is needed in the evaluation of conditions where they can be expected to prove of service, and intelligent operation is required. Average filter runs were increased from 14 to 52 hours at Belleville, and the number of washes were cut to ¼ of their former frequency (Scriven, 1960). About 1¼ percent of production was required to wash the microstrainers.

Turre (1959) reported that a microstrainer had been installed at the Marston Lake South Side Filter Plant, Denver, Colo., and that microorganism removals exceeded 91 to 95 percent.

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* Nelson, O. F., K. M. Mackenthun, and L. A. Lueschow, 1961. Microstraining at Kenosha. Paper Presented at Wisconsin Section, American Water Works Association, Milwaukee, Wis. (Sept. 28) 15 pp. (mimeo.).

Corrosion Problems

Algae sometimes contribute to corrosion either directly in localized places where they may be growing or through their modification of the water by physical or chemical changes. Green and blue-green algae, growing on the surface of submerged concrete, have caused the concrete to become pitted and friable. The effect has been most pronounced when the percentage of SO_3 in the mortar was 0.6 or higher. It has been assumed that the gelatin present in the living plants, together with the carbonic oxalic, and silicic acids produced by them, are adequate to corrode the cement (Oborn and Higginson, 1954).

Algae have been reported to cause corrosion in metal tanks and basins open to sunlight. *Oscillatoria* growing in abundance in water in an open steel tank has caused serious pitting of the metal. The pits were bright and clean, the iron apparently going into solution and not producing any covering compound such as an oxide or sulfide. The algal growth permitted the pitting to take place by releasing oxygen which combined with the protecting film of oxide over the steel. When the steel tank was covered to prevent entrance of light, the algae disappeared and the corrosion stopped (Myers, 1947).

Indirectly, algae may affect the rate of corrosion in a number of ways. Increases in organic deposits in the pipe, increases in the dissolved oxygen in the water through photosynthesis in the raw water supply, and changes in the pH, CO_2 content and calcium carbonate content of the water can all be stimulated by algae. Such changes can, in turn, affect the rate of corrosion.

Algae on Reservoir Walls

Drastic measures often have to be taken to control the attached algae, especially if the growths are neglected until large quantities threaten to cause trouble. One city adapted a floor-cleaning machine, fitted with a cylindrical wire brush, for use in scraping the algal growth from the concrete floor of a 13 million gallon reservoir. The machine proved to be much more effective than hand scrapers in removing the attached portions of the algae from the more than 100,000 square feet of concrete. The detached algae were then flushed from the reservoir floor by streams of water from a fire hose (Kuran and Angell, 1953). The use of chemicals to kill attached algae when they are present in quantity may not solve the problem because dead algae, as well as living ones can clog filters and screens, release slimes into the water, and cause tastes and odors.

Iron Bacteria

The development of iron bacteria may manifest itself in several ways. There may be hard deposits that tend to fill up pipes and reduce their water-carrying capacity. Slimes and accumulations of filamentous bacteria may form on the walls of pipes and water holders and scums may be produced on the water surface. These bacteria may cause turbidity and discoloration of water and be responsible for some of the unpleasant tastes and odors that are produced either directly or indirectly as the dead bacterial cells are decomposed by other microorganisms. Water color may be used as a very rough criterion of abundance because very clear water may reveal only 1 or 2 organisms per milliliter, whereas the number of organisms in reddish and turbid waters may exceed 10 million per milliliter (Lueschow and Mackenthun, 1962). From the examination of 76 municipal wells in Wisconsin, 53 percent revealed iron bacteria at various concentrations. Generally, *Gallionella* sp. occurred more regularly than *Leptothrix* sp., and usually in greater numbers. Iron concentrations did not appear to be related to the occurrence of iron bacteria, but very high concentrations of iron bacteria revealed substantially higher concentrations of iron than the general mean. The occurrence of iron bacteria in the distribution systems was considered independently from the occurrence in wells. Generally, the occurrence was under 100 organisms per milliliter, but two outlets revealed concentrations as high as 10 million organisms per milliliter. These two samples were from a fire hydrant and a relatively unused tap. Under circumstances of high organism population, the water contains a dense red sediment, and settling indicated that ¼ to ⅓ of the sample volume was iron or iron bacteria.

Harder (1919) reports active development of iron bacteria in pipes carrying water with 1.3 mg./l iron. Halvorson (1931) found them in springs having 1 to 10 mg./l. Schorler (1906) records incrustation of 3 centimeters thickness in pipes carrying water with from 0.2 to 0.3 mg./l iron during 30 years of usage. The amounts of nitrogen required by iron bacteria are very small compared to the requirements for iron and it is probable that the nitrogen content of most waters meets their needs.

Chlorination of water appears to be the most satisfactory method to control the development of iron bacteria (Clark, 1963). Duchon and Miller (1948) found that chlorine and hypochlorite were the most effective chemical agents to control growths of *Crenothrix*. Blair (1954) stated that maintaining free residual chlorine throughout the distribution system was an effective means to combat infestation. He warned that even though the kill was effective, tastes and odors were still possible.

Animals

Published records describing animal infestations in distribution systems in the United States are meager. The modern water treatment plant with coagulation, sedimentation, rapid sand filtration, disinfection and subsequent storage in covered clear wells and distribution reservoirs has done much to minimize household infestations. Finished water stored in uncovered distribution reservoirs, however, may mitigate the elaborate steps in purification at the water treatment plant. Treated water can be degraded by dirt, lawn fertilizers, leaves, or other organic contaminants entering the open reservoir. Such materials increase fertility and initiate organism food chains similar to ones that may develop in raw water. Thus, immature and adult animals, as well as algal cells, pose potential, if not always actual, infestation dangers to the consumer. Water supply systems lacking filtration prior to storage in open water reservoirs foster maximal nuisances to plague the householder.

Animals that have been reported in distribution systems and that are of special interest to the water works operator, and in certain instances to the consumer are: nematodes (roundworms), mollusks (snails and clams), midge larvae (bloodworms), and crustacea (copepods and water fleas). Other animals causing occasional nuisances in distribution systems are: protozoa, sponges, rotifers, bryozoans, segmented worms, and aquatic sow bugs (water lice). Animal infestations have been less frequently reported in recent years. Walton (1930) has reviewed early literature on organisms in water supplies.

BLOODWORMS

Bloodworms, *Chironomus* sp., have been reported in an uncovered clear well of Cincinnati's water treatment plant (Bahlman, 1932). Larvae moved from the clear well to emerge through faucets of residences on the distribution system. During the infestation, 10 or 15 worms were carried to a bathtub and 25 were taken from a finished water faucet at the filtration plant in 24 hours. Others emerged from faucets or entered toilet bowls of a suburban hotel. The infestation was associated with a prolonged drought, flourishing algal growths, and leaves and black sludge on the reservoir's bottom that was 10 to 12 inches deep and contained 50 percent ash and 42 percent volatile and combustible matter. Bahlman concluded that ". . . a complete covering of the clear-well reservoir is the only means of maintaining an aesthetic water supply."

Brown (1933) discussed a bloodworm infestation in a distribution system and found the point of development to be a reservoir of the Stockton, Calif., potable supply. The reservoir had a collapsed roof.

Hechmer (1932) reported bloodworms, *Chironomus plumosus,* from finished water tanks, coagulation basins, and the surface of sand filters of water treatment installations of the Washington Suburban Sanitary District (Washington, D.C.-Maryland). None got through the filters. Bloodworms found in the finished-water tanks developed there from eggs deposited by the adult midge flies. Larvae issuing from faucets caused consumer complaints. Covering the filtered-finished-water tanks did away with the bloodworm problem. Attempts to kill worms with high doses of chlorine (10 p.p.m.) and copper sulfate met with no success.

Hastings (1937) discussed the destruction of the film on a slow sand filter in Belgium by *Chironomus* midge larval tubes at the surface of the filter. When these insects emerged, empty tubes allowed water to pass through unfiltered. On one occasion, swallows that were feeding on emerged midge adults were taken as a warning to stop filtration until a new film could be formed.

Rapid sand filters, which are bound to collect organic debris in the interstices between sand grains, may present an ideal home for breeding segmented worms. Worm populations in rapid sand filter beds have been reported to necessitate washing the beds with a strong solution of caustic soda (Hobbs, 1950).

Silvey (1956) states, "One may actually anticipate the appearance of these immature midgeflies in any water supply that does not have ample means of flocculation, sedimentation, and filtration." He listed the lethal concentrations of a number of insecticides including copper at 10 p.p.m., chlorine at 7 p.p.m. and copper-chlorine-ammonia at 4 p.p.m. The latter, with a chlorine residual of 3 p.p.m., was lethal in 24 hours.

An unidentified chironomid was eliminated from the Alexandria, Va., distribution system following surface spraying of reservoirs with DDT at 0.01 p.p.m. in Triton X and Xylene on August 31, 1945 (Flentje, 1945). In another paper, Flentje (1945) reviews control measures for pest infestations in public water supplies. He lists mechanical, biological, and chemical controls. Mechanical controls include covering the reservoirs, screening of all vents and openings with small mesh screen to exclude female midges, and the use of excelsior filters placed over outlet pipe in reservoir to prevent organisms from entering the water main. He recommended a filter 6 feet by 3 feet by 3 feet 6 inches and states that it effectively stopped crustaceans and other organisms from entering the system. Filters can be used without exchange for 4 months or longer. Biological controls involve keeping vegetation down in the vicinity of reservoir and controlling algal growths to remove food source. Flentje stated that ordinary chemical treatments used in water works operations were not effective in the control of midge larvae. He found that larvae could withstand chlorine concentrations as high as 50 p.p.m. with a contact period of 24 hours. Fifty p.p.m. of copper sulfate was ineffective in control and 13 p.p.m. of chlorine was lethal in 1½ hours; copper sulfate added with chlorine hastened the killing time. Mineral oil has been used to keep air from eggs and to prevent pupae from flying away. DDT at 0.01 p.p.m. gave excellent results but it should be considered only in unusual cases and should not be used without full approval of proper supervisory public health authorities (Flentje, 1945).

Microstrainers at a cost of $43,500 per m.g.d. for installation and $2 per m.g.d. for operation were installed in a Connecticut water supply to control invading Chaoborinae (phantom midge) larvae (Wilbur, 1961). Water was supplied from reservoirs, which receives copper sulfate for algal control, and breakpoint chlorination was practiced as the water flowed to the distribution system.

HYDRA

Hydra have been a problem at a Detroit filtration plant where water was received from Lake St. Clair (Hudgins, 1931). From 1923 to the early 1930's, hydras in the water entering the plant were correlated with the lake's turnovers occurring for a few days in April and in mid-November. With death and decay they formed a pinkish coating on filter walls and gave off a fishy odor if filters were not washed often. Filter runs were reduced by as much as ⅓ at the height of the invasion.

WORMS

Kelly (1955), using a small microstrainer to concentrate filter effluent, found that immature, microscopic *Naias* worms passed through slow-sand filters in numbers; none was found from rapid-sand filters. Slow-sand filters passed *Naias* worms, *Cyclops, Daphnia,* various diatoms, nematodes, rotifers, and a few flatworms *Stenostromum.* Rapid-sand filters yielded only a few diatoms. No way was found to prevent organisms from passing through the slow-sand filters. A chlorine dose of 200 p.p.m. failed to destroy nematode eggs in several days, and as much as 20 p.p.m. of chlorine was required to kill adult nematodes in 2½ hours. To alleviate the problem, microstrainers and a large chlorination contact tank with provisions for superchlorination and for dechlorination with sulfur dioxide were installed following the period of contact.

NEMATODES

Motile microscopic nematode larvae at densities of 1 to 20 per gallon, and on one occasion up to 100 per gallon, were found in the distribution system of an unnamed city using the Ohio River as a water supply source (Chang et al., 1959). The infestation was traced to the raw water and breeding places in sedimentation basins and rapid-sand filters. The raw water was chlorinated to a free residual of 1 p.p.m. or more and settled in basins that provided 2 day's detention. Ten p.p.m. of alum was frequently applied prior to sedimentation, then the water was flocculated with 10 p.p.m. ferric sulfate, settled, and filtered. Activated carbon was applied prior to second flocculation and chlorine was added to maintain a residual of 0.75 to 1.0 p.p.m. at the filters. Anhydrous ammonia was finally added to convert the free residual chlorine to a combined residual chlorine before the water entered the distribution system. Rapid sand filters were ineffective in removing larval worms. Most worms were killed by free residual chlorine or removed by flocculation and sedimentation, but when large numbers were carried in the river water, the females survived chlorination and settled to the bottom of the raw-water line to infest the supply with young. The authors reported that larvae and adult worms can injest pathogens such as *Salmonella, Shigella* and *Coxsackia* A9 virus and protect them from the destructive action of the free residual chlorine.

Chang et al. (1960), following a survey of free-living nematodes and

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amebas in municipal supplies, reported that 16 of 22 supplies in as many States contained nematodes in both raw and finished water. Fourteen of the 16 used river water as a raw source.

Change (1962) discussed possible control measures on a plant scale basis, stating:

> "At present it appears that the most practical method for preventing nematode infestation is to prechlorinate the raw water for 6 hours; a free residual of 0.4–0.5 p.p.m. chlorine should result at the end of this period. Although many of the nematodes are not killed, they are sufficiently affected so that they can no longer swim; therefore, they will be settled out in the flocculation process. The pH, in the range of 6.0–8.2, appears to have no detectable influence on the vermicidal activity of the free chlorine."

COPEPODS AND ASSOCIATES

Water fleas in finished water in distribution systems have been reported by Hart (1957). He implied that the cyclops eggs, rather than the adults, pass through filters, which accounted for the appearance of mature forms in potable supplies.

Indianapolis reported an epidemic of copepods in the distribution system during January 1953, and in 1954 (Crabill, 1956). Eggs passed through the filters and hatched in the finished water. As many as 20 eggs per liter were counted from the finished water at the immediate effluent side of the filter. Structural faults that permit insects to deposit eggs directly in purified water may be responsible for the infestations, and open reservoirs on distribution systems are an invitation for trouble.

Crabill reported that a copper-chlorine-ammonia treatment applied to obtain a copper residual of 3 p.p.m. and a combined chlorine residual of 0.5 p.p.m. will kill adult copepods in less than 5 hours. Copper-chlorine-ammonia having 2-p.p.m. copper residual was equally effective in 12 hours, and 1 p.p.m. Cu was effective in 24 hours. The combined chlorine residual remains 0.5 p.p.m. in all three copper strengths. Organisms are killed as they emerge from the eggs. Nothing was found that would penetrate the egg sac or the individual egg and prevent it from rupturing and giving up an active organism.

WATER LICE

In 1958 in flushing water mains through coarse muslin bags for 10 minutes each on the Great Yarmouth, England, supply, 230 out of 400 points investigated discharged 6 to 8 *Asellus aquaticus.* At one point up to 1,000 organisms were found (Phillips, 1968). To control the organism, the plant water was dosed with pyrethrum at 0.002 p.p.m. for 21 days. Prior dechlorination with sulfur dioxide was necessary because chlorine inactivates pyrethrins. Every hydrant was flushed 3 times during the treatment to draw the treated water through. Service reservoirs and water towers were also treated, with the water wasted following treatment. No specimens have been detected in the mains since 1959. Phillips concludes that a contact tank chloramine residual of over 1 p.p.m. entering and 0.5 p.p.m. leaving after a minimum contact time of 2 hours was the best control available with chemicals presently in use. He stated that until new methods are developed, it is unlikely that organisms can be completely eliminated.

Phillips used pyrethrins at a maximum dose of 0.01 p.p.m. for short periods and noted that this concentration was not noticed by consumers. Oliver (1961) reported that pyrethrins at 0.012 p.p.m. was effective in eradicating *Asellus* that were often found to block a small filter receiving raw water through a main.

In September 1964, *Asellus aquaticus,* originating from the river Elbe, colonized the water-distribution system at Magdeburg, East Germany, and reached a count of 2,490 animals per m ^{3} of water (Klapper, 1966). The organisms were completely destroyed by treating the water leaving the water works, for a period of 5 days, with an alcoholic solution containing 1 percent pyrethrin extract (25 percent pyrethrin) and 2.5 percent piperonyl butoxide (as a synergist), a concentration of 0.0025 mg of pyrethrin per litre of water. This led to an unexpected high increase in the bacterial count throughout the distribution system, and the pyrethrin treatment was therefore followed by treatment for 7 days with 2 to 3 mg. of chlorine per litre and for a further 14 days with 1 mg. of chlorine per litre. To prevent a fresh outbreak of *Asellus* in May 1965, when thick colonies formed on the filters at the water works, the filters were treated with alcoholic pyrethrin extract; this caused no problems since the pyrethrin is removed by the subsequent chemical coagulation process and no poison reaches the treated water.

SPONGES

Morgan (1930) stated that water pipes are often lined with rough coatings of sponges a quarter of an inch or more thick and that the incrustation hindered the flow of water through the pipes or sometimes stopped it.

CLAMS AND SNAILS

Sterki (1911) records an infestation of the Erie, Pa., water system when the raw source was Lake Erie. The intake at the time was 4 to 5 miles out in the lake. He noted that "wagon-loads" of snails were taken from the crib structure when it was cleaned and that snails often plugged faucets. Two genera of snails that were collected with *Bythinia* but not reported to cause nuisances were *Physa* and *Helisoma*. Published data relating to difficulties caused by snails and clams in drinking water supplies are meager. Ingram (1956) reviewed 30 references that relate snails to drinking water supplies; most of these report infestations but do not discuss control measures to alleviate nuisance. Records deal principally with the faucet snail, *Bythinia tentaculata* (Linnaeus).

Clam nuisances have not yet been reported in distribution systems in the United States; one species, *Corbicula fluminea,* introduced from Asia and bordering Pacific Islands, has been recorded as causing trouble in raw-drinking water supplies and in the canal transportation system of the LaVerne water softening plant of the Metropolitan Water District of Southern California (Ingram, 1959). This clam has a life cycle that, in prognostication, should eventually cause it to be listed as a nuisance in treated supplies. It is established as a pest in pipes of irrigation systems in California. Since the time of the first published record of its distribution in the United States as an inhabitant of certain streams in California and Washington, it has spread to waterways in Arizona, Oregon, Idaho, Tennessee, and Ohio.

CONTROLS

In 1960, the American Water Works Association answered questions from water works operators on biologic infestations. In response to a question on how to control *Cyclops* infestation, the committee answered that an identical problem was corrected by flushing water mains and following with an application of cuprichloramine over a 3-week period (Crabill et al., 1960). This treatment killed *Cyclops* emerging from the eggs, which had passed the filters and hatched in the system. On controlling growths of blue-green algae inside water mains and the actinomycetes that may grow on the blue-green algal remains, chlorine dioxide at 2.5 p.p.m. was recommended. Treatment should be done in cooperation with agencies familiar with the process since low residuals are detrimental to fish and laundry processes. The committee stated, in response to another question, that caddisfly larvae frequently pass from the raw water into the intake pipe and build cases of sand grains, plant remains, debris, etc. Over a period of time these cases may pile towards the center of the pipe and constrict the flow. The committee stated that those organisms may be controlled by adding 5 to 8 p.p.m. chlorine for 10 minutes per day until organisms are killed.

Geist Reservoir

A limnological study was made of 1,800-acre Geist Reservoir, serving Indianapolis, Ind., during 1963 and 1964.* The reservoir is owned by the Indianapolis Water Co. and is used principally as a water storage impoundment, although limited recreational use was permitted. Fishing was the principal form of recreational use, and 515,000 man-hours per year were spent in fishing activities on the reservoir. Water skiing, swimming, and use of large horsepower motor boats were prohibited. Objectives of

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*** Indiana Water Quality-Recreation Project, Geist Reservoir, Indianapolis, Ind. Department of Health, Education, and Welfare, Federal Water Pollution Control Administration, May 1966.**

the study were to evaluate possible deterioration in water quality that result from use of a watershed or reservoir for recreational purposes, and to determine the effects of water pollution sources within the drainage basin on water quality.

Geist Reservoir is 7.5 miles long; it has a shoreline of 35 miles, and stores 6.9 billion gallons of water. It has a maximum depth of 30 feet and is divided into three unequal basins by two causeways. The watershed draining to the impoundment is 215 square miles; the surrounding land is used primarily for farming and is gently rolling to flat "Wisconsin" glacial-drift. During the spring runoff period (March through May), the average turbidity was 155 units for the influent and upper causeway stations (fig. 66). A large portion of the particulate matter settled out in the reservoir; the mean turbidity was 30 units at the dam station. During the spring period, maximum turbidity readings were 950 units at the inlet and upper causeway stations and 75 units at the dam station. The decrease in turbidity with both time and distance from the influent is shown in Figure 66.

The reservoir received a flushing during March and April when it received 90 percent of its influent water. During the low flow period, August through January, the influent was less than 25 million gallons per month. The outflow of water from Geist Reservoir was greatest during the two spring months, March and April. After the reservoir had reached its

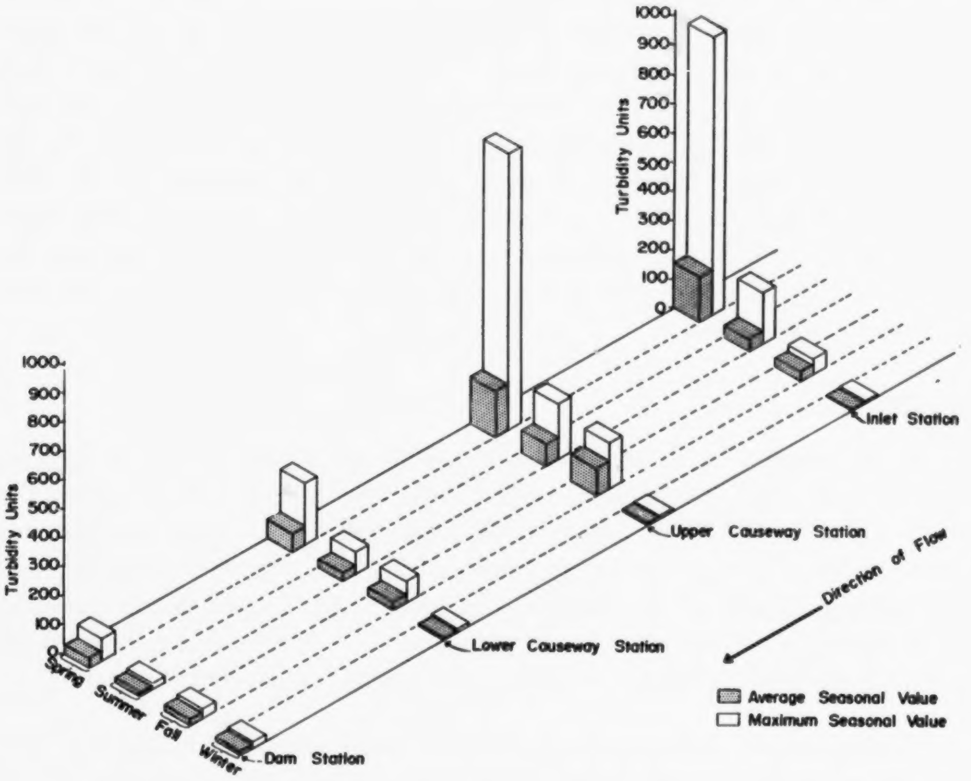

Figure 66. Seasonal turbidity unit values, Geist Reservoir, 1963–64.

storage level, the drawoff was subject to the demands of the water company. Minimum reservoir volumes of 4,500 million gallons were observed from November through February.

Vertical water temperatures and dissolved oxygen concentrations were determined at selected points throughout the reservoir during the spring and summer of 1964. Between the dam and the lower causeway stations, temporary thermal stratification was exhibited from June through August during periods of calm weather (fig. 67). The euphotic zone (that portion of the reservoir in which there is sufficient light for photosynthesis) was approximately 10 feet and contained up to 18 mg./l of dissolved oxygen (D.O.). The layer of water varying from 2 to 10 feet above the bottom contained less than 0.5 mg./l D.O. during June and July, 1964. During the routine sampling in 1963 and 1964, D.O. concentrations and water temperatures were recorded at a five-foot level at four reservoir stations. These data show that the supersaturated dissolved oxygen concentration in the upper-water layer was the result of photosynthesis and the low dissolved oxygen concentrations in the bottom water layer resulted from the respiration of settled organisms and the decomposition of wastes entering the reservoir.

Inorganic nitrogen (NH_3-N, NO_3-N and NO_2-N) and soluble phosphorus were always present in large quantities even during the maximum algal growing season in June. By calculation, 793,000 pounds per year of inorganic nitrogen entered Geist Reservoir and 443,000 pounds flowed out; the difference between these two values indicated 44 percent reten-

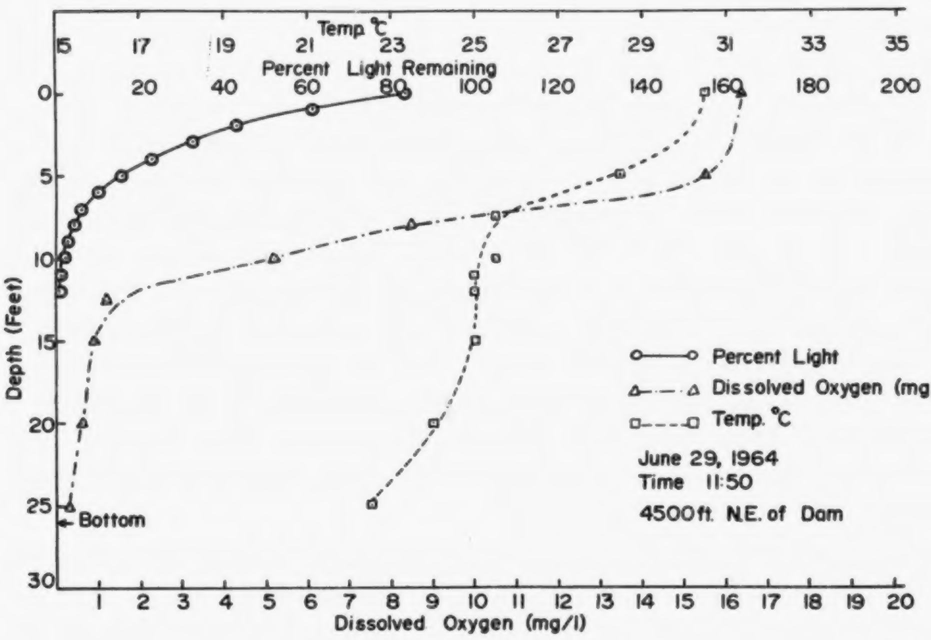

Figure 67. Vertical temperature, dissolved oxygen, and percent light, Geist Reservoir, Ind.

tion. Geist Reservoir contained an average inorganic nitrogen concentration of 1.2 mg./l, based on the mean monthly quantity of inorganic nitrogen divided by the mean reservoir volume. The season of major runoff (March and April) accounted for 633,400 pounds of inorganic nitrogen entering, and 375,000 pounds or 59 percent of the total annual inorganic nitrogen inflow leaving Geist Reservoir.

The total amount of inorganic nitrogen present in Geist Reservoir during March was 128,000 pounds. This quantity steadily decreased through July. From August through December Geist Reservoir contained, at all times, at least 10,000 pounds of inorganic nitrogen that was available for algal production. By calculation, the drainage area was supplying 3,690 pounds of inorganic nitrogen per square mile of drainage per year. This loading is equivalent to 440 pounds per surface acre in the reservoir per year.

On an annual basis, 51,000 pounds of total phosphorus, of which 38,000 was soluble, entered Geist Reservoir. The outflow was 38,000 pounds of which 23,600 was soluble. This provides a 25-percent retention of total phosphorus and a 38-percent retention of soluble phosphorus. The average annual concentration of soluble phosphorus (P) in Geist Reservoir was 0.06 mg./1. By calculation, 61 percent of the annual soluble phosphorous entered Geist Reservoir during March and April, and during that same period 90 percent of the soluble phosphorus was discharged. During the period of maximum algal production (June) the inorganic nitrogen concentration was 0.39 mg./1. and the soluble phosphorus concentration was 0.39 mg./l and the soluble phosphorus concentration was 0.014 mg./1, which indicated that these nutrients were not completely utilized.

By calculating the reservoir volume and the concentration of soluble phosphorus, the pounds available for algal production can be estimated. During the month of April, an average quantity of 6,800 pounds of soluble phosphorus was available. This quantity was reduced to 2,000 pounds during May and June. The minimal level of soluble phosphorus occurred during July of both 1963 and 1964 when 900 pounds of soluble phosphorus was available for algal production in the reservoir. During August to December Geist Reservoir contained approximately 2,000 pounds of soluble phosphorus. During 1963 and 1964, the percent soluble phosphorus of the total phosphorus ranged from a minimum of 25 percent to a maximum of 71 percent, and averaged 45 percent. The drainage area supplied an average of 240 pounds of total phosphorus per square mile. (See table 3 for comparative data.)

During the spring, Geist Reservoir supported 458-pounds per acre (wet weight) of phytoplankton; and in summer, 960-pounds per acre. The fall and winter standing crops were (on the average) very similar to the spring phytoplankton standing crop, namely, 484 and 213-pounds per acre respectively. Volumetrically, the lower causeway station was richest in phytoplankton with the exception of the fall period (fig. 68). Phytoplankton volume was least at the inlet station and greatest in the shallower pools formed by the two causeways. In these areas turbidities are reduced and nutrients are readily available.

In figures 66 and 68, good use was made of the three-dimensional method of data expression. Stations, as well as displayed data, were few in number and the resultant displays can be interpreted readily by the viewer.

The benthic population in the middle basin reached a maximum of 1,180 organisms per square foot. Sludgeworms predominated in the benthos with 950 per square foot. The benthic population in the lower basin contained a maximum of 2,600 organisms per square foot and, like that in the middle basin, was predominantly sludgeworms. Sludgeworms and phantom midge populations were significantly higher in the lower basin than in the upper basin. Higher phantom midge populations in the lower basin were attributed to the deeper water, which reached a maximum depth of 30 feet.

The composition and magnitude of the benthic population in Giest Reservoir was similar to those usually associated with a moderately productive water body. Physical factors such as temperature, fluctuating water levels, depth, and bottom types influenced the bottom organism population to such an extent that any moderate increase in recreation or land development would be insignificant in effecting changes.

From the study of this water supply reservoir, it was concluded that:

(1) the fertile drainage area supplied sufficient nutrients and growth stimulants to Geist Reservoir for aquatic vegetation development, and that the effects from any nutrient increases resulting from currently proposed recreational use or adjacent land development would be undetectable,

(2) the nutrients and growth stimulants supplied from the drainage area were contributed by agricultural runoff, municipal-industrial discharges, and forest and noncrop land runoff. A reduction in agricultural, municipal, and industrial wastes could improve water quality,

(3) gross mineral analyses indicated an acceptable water quality for a public supply, and

(4) analyses of data from chemical and biological determinations conducted on Geist Reservoir during 1963 and 1964 indicated that the small amount of recreation present on Geist Reservoir had a minimal, insignificant effect on the present water quality.

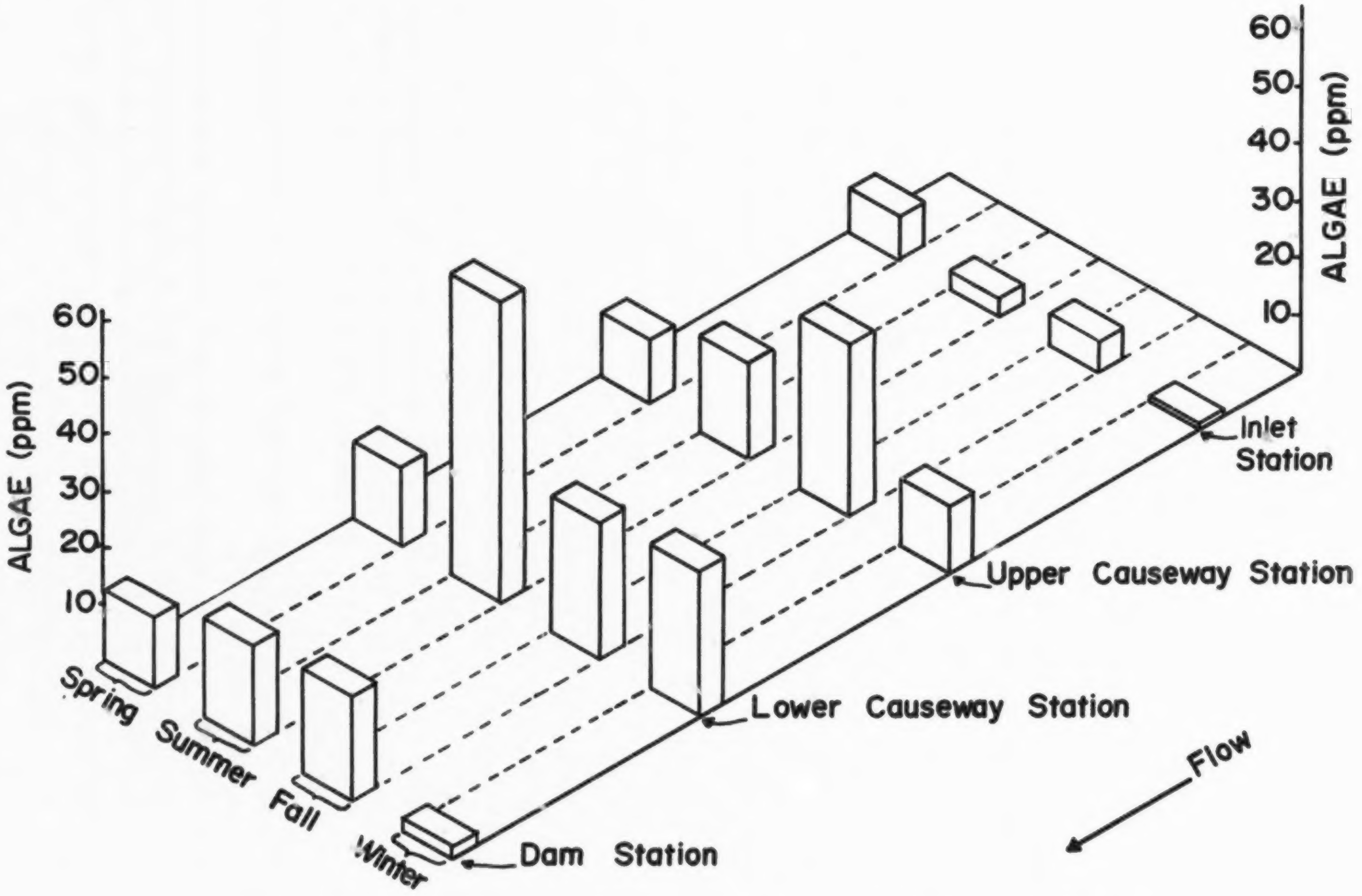

Figure 68. Concentration of phytoplankton (p.p.m.), Geist Reservoir, 1963–64.

13

WASTE TREATMENT

MUCH of sewage treatment is a biological process. Plants in waste treatment are restricted mostly to bacteria and the higher fungi. When the operation proceeds in light, green filamentous algae, green non-filamentous algae, or flagellated organisms thrive. Blue-green algae may also be present, although generally not in large numbers. Perhaps the least helpful of the common groups of algae in sewage treament are the diatoms. Many bacteria and fungi will grow in light, but their preferred habitat is a dark one and they, therefore, work in the depths of filters, Imhoff tanks, digesters, or the interior of sand filters. Sunlight is necessary for the growth of algae, and most algal forms require about 6 to 7 percent of full sunlight to carry on active growth.

Most of the lower plants and animals found in sewage treatment are cosmopolitan in occurrence. They are well known and seem to be substantially alike in similar treatment plants. Some organisms, however tend to occur very abundantly in certain types of wastes so much so that blooms of them can be called indicative for the waste and for the condition it causes. The dominance of a particular species is in response of the organism to some particular component or condition of the waste. Only a few chlorophyll-containing types can utilize the dissolved organic substances in sewage, raw or partly digested, and these then become of value as indicators of particular conditions. The great majority of algae prefer to thrive in waters low in organic matter, and utilize phosphorus, carbon dioxide, nitrates, oxygen, and other inorganic substances.

Bacteria and other colorless plants initiate the breakdown of organic substances, and while particular organic substances are attacked by particular species, generally there is a large number of bacterial species in any waste disposal unit. At the present time there is far too little knowledge of either the work done by individual species or on the use of particular types for purification of particular wastes.

Visible active inhabitants of anaerobic habitats, Imhoff tanks and digesters, are generally bacteria, together with about 20 species of protozoa divided equally among flagellates, ciliates, and amoeba. None of these generally are present in large numbers, and often the protozoa are extremely scarce. It has been stated that it is probable that these organisms afford a fair criteria to the proper working conditions in an Imhoff tank. When the tanks foam or seem to digest poorly, the number of protozoa is high, and when there is but little solid matter in the liquid, the number of protozoa tends to be small.

Conditions in filters and aeration chambers are less severe, and the animal populations are usually larger. Here it seems well proven that animals exert a decided influence by consuming bacteria to the extent that the bacterial population curve never levels off. The bacteria are always growing and reproducing, and this is their most effective stage in purification. Also certain insect larvae burrow in the film of filters, thereby keeping it loose and porous and capable of unloading.

A complete list of the animals in trickling filters would comprise some hundreds of species that would include psychoda flies, several genera of worms, roaches, snails, other insect larvae, and many species of protozoa. Activated sludge contains much less diversity of fauna, but does frequently contain branching fungi and filamentous bacteria.

Protozoan fauna are abundant and are usually dominated by solitary or colonial Vorticellidae. Other ciliates may occur in large numbers. There are a few flagellated species and amoeboid protozoa. Rotifers, nematodes, and annelid worms may become very important.

Agersborg and Hatfield (1929) described the biology of sewage treatment and, in particular, their studies on the Decatur, Ill., plant. They listed organisms found in Imhoff tanks, trickling filters, and aeration tanks. Arden's (1928) summary of the protozoan characteristics of activated sludge was cited. He found that sludge in "bad condition" contained a preponderance of flagellates, many amoeba and relatively few ciliates. Sludge in unsatisfactory condition contained flagellates and amobea and some ciliates. Sludge in satisfactory condition supported few flagellates and amoeba and contained a preponderance of ciliates. Sludge in good condition supported very few flagellates; amoeba were rare, and there was a proponderance of ciliates. Lackey (1949) reviewed the biology of sewage treatment and considered both the anaerobic and aerobic systems. Calaway and Lackey (1962) described in taxonomic detail the flagellates associated with waste treatment.

Trickling Filters

The biotic populations of the trickling filter are relatively uniform in composition. Bacteria, fungi, protozoans, algae, nematodes, rotifers, snails, sludgeworms, and larvae of certain insects may vary from filter to filter at the species level, but the biota remains relatively constant. Identification of the members of this population has been of little concern to the sanitary engineer as long as the population became established and functional relatively quickly after placing a filter in operation. A good operating condition is one in which little clogging occurs in the spaces between stones and one which carries on its function of removing solid, colloidal, or dissolved materials from the sewage, thus its biochemical oxygen demand (BOD) is reduced.

In 1939, Reynoldson made a very thorough study of segmented worms in bacteria beds in England. The most important species was considered to be *Lumbricillus lineatus* while *Lumbricus rubellus* was also abundant. Usually adults were found at lower levels while the young were near the surface. Their feeding habitats were closely associated with the growth of *Phormidium* sp. on the surface film. Drying conditions in summer and cold temperatures in winter tended to send these animals deeper into the filter beds. The cycle of their appearance indicated that they were responsible for sloughing. As the algae returned after 3–4 weeks the worms moved upward to feed upon this growth. The more rapid regeneration of the algae in the summer was also attributed to the effects of the worms. The value of the worms in developing sloughing conditions and in controlling the film was demonstrated experimentally. In the filters under study the worms were considered as important as the insect larvae in controlling accumulative film growth.

Wilson (1943, 1949) reported that scouring organisms such as oligochaete worms and insect larvae were important in preventing excessive development of film and increasing plant efficiency in Wisconsin and Minnesota. The worms listed included: *Aelosoma hemprichi, Pristina* sp., and *Dero* sp. He stated that while worms such as *Dero* were few in number they exerted a potent influence on the reduction and stabilization of sewage solids and assisted in clearing voids among rocks for the improvement of ventilation.

Imhoff and Fair (1956) indicated that among the worms present in trickling filters were the "aquatic earthworm" *Limnodrilus* sp., and the reddish sludge worm *Tubifex* sp.

Usinger and Kellen (1955) studied the role of insect in several types of sewage disposal beds in California. In an experimental biofiltration plant at San Rafael Meadows insect larvae were found. The commonest species was a member of the Diptera, *Psychoda alternata*.

In certain areas, populations of snails can develop in trickling filters. Ingram et al. (1958) have reported that at least five species of snails have been found in the United States on trickling filters. *Physa anatina* was found at Urbana-Champaign, Illinois, *Physa halei* at Fort Worth, Texas, *P. cubensis* at Gainsville, Flordia, and *P. integra* at Dayton and Hillsboro, Ohio. In addition, *Lymnaea humilis modicella* was found once in low numbers at Urbana-Champaign. Serious damage to equipment was reported as a result of the activities of *P. integra* at Dayton, and of *P. cubensis* at Gainsville.

Cooke (1959) published a composite list of more than 200 known organisms found in trickling filters.

Twelve tubular perspex experimental filters, each 91 cm. high and 15 cm. in diameter, were used by Williams and Taylor (1968) to determine the effect of *Psychoda alternata* (Say) and *Lumbricillus rivalis* (Levinsen) on the efficiency of sewage treatment in percolating filters. The volume of each filter was 16.7 liters and all were filled with sterilized 1.3 to 1.9 cm. clinker. Ventilation was provided by two ports, covered with fine gauze, one at the top and one at the base of each filter. A constant temperature of 15° C. was maintained during the experiments.

Artificial sewage, with BOD and organic carbon values of about 350 mg./l and 180 mg./l respectively, was introduced with an initial loading equivalent to 80 gal./yd.^{3} per day and 0.16 lb. BOD/yd.^{3} per day, and was increased to 100 gal./yd.^{3} per day and 0.35 lb BOD/yd.^{3} per day. Three species of fungi and 6 species of protozoa were introduced at the start of the experiment. Each of 4 groups of triplicate filters received fly larvae at a density of 17 larvae/l, worms at a density of 24 worms/l, a mixture of both fly larvae and worms, and no macrofauna respectively.

The film in the control group grew rapidly, blocked the filter, caused ponding and produced anaerobic conditions. The efficiency of treatment, measured in terms of BOD and organic carbon removal, decreased from 90 percent to 40 percent. The two groups containing fly populations had treatment efficiencies greater than 90 percent within 2 months with the larvae successfully controlling the film accumulations. The filter group containing worms achieved similar high treatment efficiencies, but not until 5 months after inoculation. The worm populations increased more slowly because of longer developmental periods.

Many wastewater treatment plants are troubled seriously by *Psychoda* flies. When circumstances are favorable, large numbers of these, especially of the species *P. alternata Say* ("the trickling filter fly") may leave the filter beds.

The *Psychodidae* are not restricted to sewage filter beds. These flies frequent decaying organic material, in which they lay their eggs. The fact that they are able to become a real pest at many treatment plants results from the favorable environment commonly prevailing in a filter bed. The relative humidity is high, sufficient oxygen is present, food for the larvae is abundant, and the pupae can find many places where they can nestle and where the imagoes can hatch.

The flies do not sting or suck blood, but they are a real annoyance because they settle on the eyes, ears, nose, and clothes, and, because of their minute size they easily enter surrounding houses. They are not known to transmit disease, but there are indications which make them suspect.

Scott (1961) presented an excellent concise bibliographic review of filter fly control. Although drying, flooding, and treatment of the slime layer with insecticide give good control, they are all unpopular with the sewage plant operator. The efficiency of the biofilter is dependent upon the activity of its slime layer. Yet, drying destroys it, flooding disrupts it, and both involve cessation of operation for considerable time. While insecticides may be applied without stopping the filter, they throw the slimelayer out of balance, and may poison aquatic life downstream from the sewage outfall. The oil present in solutions and emulsions does serious damage to the slime layer, so suspensions are used in treating the filter bed. However, even suspensions kill off large numbers of key organisms (including filter fly larvae which are in themselves important), and therefore lower the efficiency of the filter.

Scott stated that the following procedures seem best for filter fly control: (1) keep weeds and grass mowed short throughout the sewage plant area; (2) spray walls and other structural elements of the filters with 2.5-percent DDT or 2.5-percent malathion suspension (at 1 gallon per 1,000 square feet using a flat spray nozzle to give a residual deposit), extending the treatment out from the edge of the filter for 20 feet, but not spraying the slime layer; (3) if necessary, spray the edges and walls of sludge drying beds with 2.5-percent DDT suspension, then take steps to improve quality of product coming from digestors; and (4) repeat treatment as needed (typically about every 2 months). Cutting of vegetation reduces favored adult-resting sites while the residual insecticide harvests adult flies rapidly so that large populations cannot buildup.

Resistance of filter flies to DDT and chlordane has been reported. If DDT resistance does appear, use 2.5-percent malathion.

Although flies are not eliminated, they persist in such few numbers that they are no longer pests. Larvae will be persent on the filter beds, and occasional small "blooms" of adults may occur.

Den Otter (1966) suggested that *Psychoda* pests could be prevented when fly larvae were hampered in their efforts to reach the surface of filter beds by use of a top layer of stones that can be rinsed easily and continuously. A 15-cm. thick top layer of pebbles, each about 5 cm. in diameter, was recommended. Continuous and complete sprinkling was obtained by recirculation and by distribution of the wastewater in jets or in sheets. Clogging was not found to be a problem.

Activated Sludge

McKinney and Gram (1956) stressed that the type of protozoan present in activated sludge was of major concern to the treatment plant operator. They stated that there is a definite succession of protozoa as activated sludge is formed and becomes more efficient. Knowledge of the various protozoa and their significance can be used as a valuable guide to better activated sludge operation. Observations of the protozoa can be made quickly with a microscope of only 100 power. These observations reflect the immediate condition of the sludge. Industrial waste systems fed unusual or toxic organic compounds require careful control to insure continuous operation at maximum efficiency. Since the protozoa are more sensitive to toxic compounds than bacteria, observations on the change in protozoa from normal levels give an immediate indication of trouble before it has had time to affect the bacteria.

Each operator must determine the protozoa characteristics of his own system and relate their activities to efficiency. A general guide as to relative predomination of protozoa and efficiency in an activated sludge system, as presented by McKinney and Gram follows:

1. *Sarcodina* (amoeba) predominate very rarely and only in systems just starting or just recovering from complete toxicity.
2. The holophytic, soluble food eating, *Mastigophora* (flagellates) predominate at low efficiency when the organic concentration is high. In some industrial wastes systems where the organic load is high, the effciency may be mathematically high but the indication is that the effluent still contains a high concentration of organic matter.
3. The holozoic, solid food eating, *Mastigophora* (flagellates) arise as the holophytic flagellates decrease. They indicate an only slightly more efficient system and efforts to distinguish between the two types of flagellates is not warranted by the results.
4. The free-swimming ciliates are found when there are large numbers of free-swimming bacteria. The efficency of the system when the numbers are very high is approximately 50 percent. They can indicate a failry efficient system or a poor one. The key is in the other types present. Flagellates and free-swimming ciliates are at the low side of the efficiency scale while the presence of stalked ciliates and higher animal forms such as rotifers indicates the high side of the scale.
5. The precense of stalked ciliates indicates an activated sludge with a low BOD effluent. The stalked ciliates arise as a result of the number of available bacteria being reduced below the demands of the free-swimming ciliates. Having lower energy requirements than the free-swimming ciliates, the stalked ciliates survive. A very stable activated sludge system will have very few stalked ciliates and, usually, no other protozoan forms. Actually, the ciliates are measuring the bacterial activity; but since the bacterial activity reflects the biochemical condition of the system, the ciliates reflect the efficiency with considerable accuracy.

Stabilization Ponds

In 1957 in the United States, there were 631 waste stabilization ponds in use in 27 States serving 2,362,842 persons, of which 430 ponds, serving a population of 759,941, were used as the sole means of waste treatment (Thomas and Jenkins, 1958). The greatest percentage increase of any treatment category during the period 1945-57 was in oxidation ponds; the number of plants increased from 45 to 631, and the population served increased from 0.2 to 2.4 million.

The use of this type of treatment continues to grow. Porges and Mackenthun (1963) reported that a total of 1,304 stabilization ponds in 39 States serving a population of 2,138,085 were used as the sole method of sewage treatment or in combination with primary treatment. It was noted that ponds were used by the larger communities to serve small populations probably until the extension of municipal sewerage to include the smaller communities. Stabilization ponds were used by 343 communities for tertiary treatment serving a population of 2,146,951 people in 27 States. Thus, a total of 1,647 ponds in 41 States were used to treat sewage from a population of 4,285,036 (fig. 69). Ponds are especially adaptable to the smaller communities since the majority of the ponds were used by those communities having populations less than 25,000. The growth of pond use is phenomenal and this treatment will probably continue.

Data indicate that 847 ponds were used by 31 industrial groups in the United States in 1962 (fig. 70). The canning industry used the greatest number of ponds with 28 percent of the reported installations. Second was meat and poultry with 21 percent. The chemical industry was next with 7 percent.

Treatment efficiencies varied with indications that well-designed and well-operated ponds produced effluents equal to or better than those expected from effective, conventional, secondary treatment plants.

Data indicate meat and poultry wastes were treated in the majority of cases by aerobic ponds. Most dairy wastes were reportedly treated by the aerobic process at relatively low loadings; petroleum wastes were also reported to be treated primarily by aerobic ponds generally at low loadings; emphasis was on phenol removal, and treatment was effective in this respect. Aerobic treatment was employed by sizable numbers of the following industries: chemical, paper, wine, textile, sugar, rendering, hog feeding, laundry, and potato processing.

Anaerobic ponds as compared to aerobic ponds were used to a greater extent by the canning, paper, textile, sugar, and leather industries. Also employing significant numbers of anaerobic ponds were the meat and poultry, chemical, wine, rendering, and potato-processing industries. Greater loadings were imposed upon anaerobic ponds with some loss in efficiency and increase in odors.

Analysis of reported data indicated that the median loading for aerobic ponds treating meat and poultry wastes was 72 pounds BOD per acre per day. Dairy wastes were more difficult to treat from an odor standpoint; the median loading was 22 pounds BOD per acre per day. Median value for petroleum wastes was 28 pounds per acre per day, although the goal for many petroleum waste treatment ponds was phenol removal rather than BOD; median phenol removal was 97 percent. Median loadings for

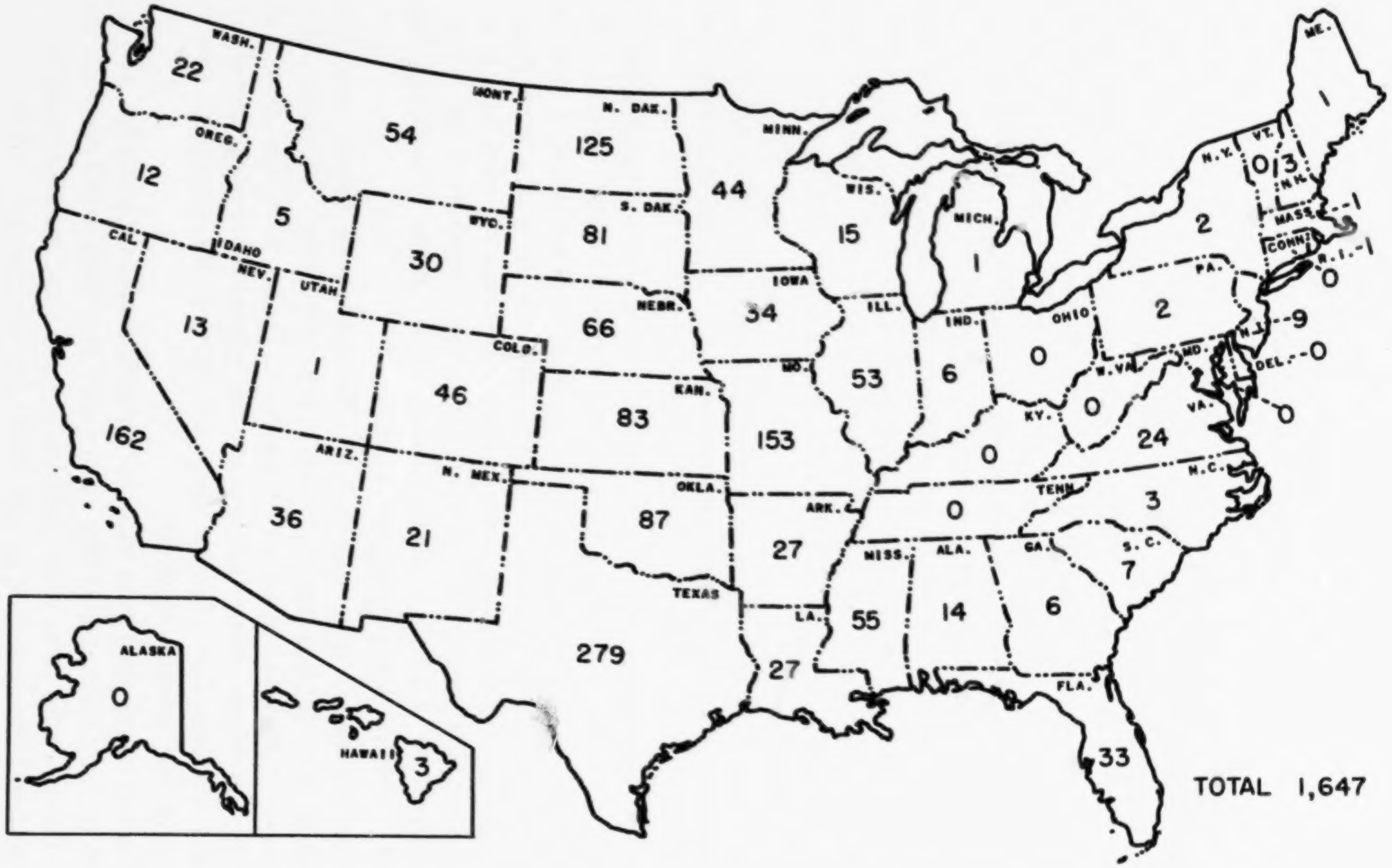
WASH. 22
OREG. 12
CAL. 162
IDAHO 5
NEV. 13
MONT. 54
WYO. 30
UTAH 1
COLO. 46
ARIZ. 36
N. MEX. 21
N. DAK. 125
S. DAK. 81
NEBR. 66
KAN. 83
OKLA. 87
TEXAS 279
MINN. 44
IOWA 34
MO. 153
ARK. 27
LA. 27
WIS. 15
ILL. 53
MICH. 1
IND. 6
OHIO 0
KY. 0
TENN. 0
MISS. 55
ALA. 14
GA. 6
FLA. 33
S. C. 7
N. C. 3
VA. 24
W. VA. 0
MD. 0
DEL. 0
N. J. 9
PA. 2
N. Y. 2
VT. 0
N. H. 3
ME. 1
MASS. 1
CONN. 0
R. I. 1
ALASKA 0
HAWAII 3
TOTAL 1,647

Figure 69. Municipal stabilization ponds in the United States—1962.

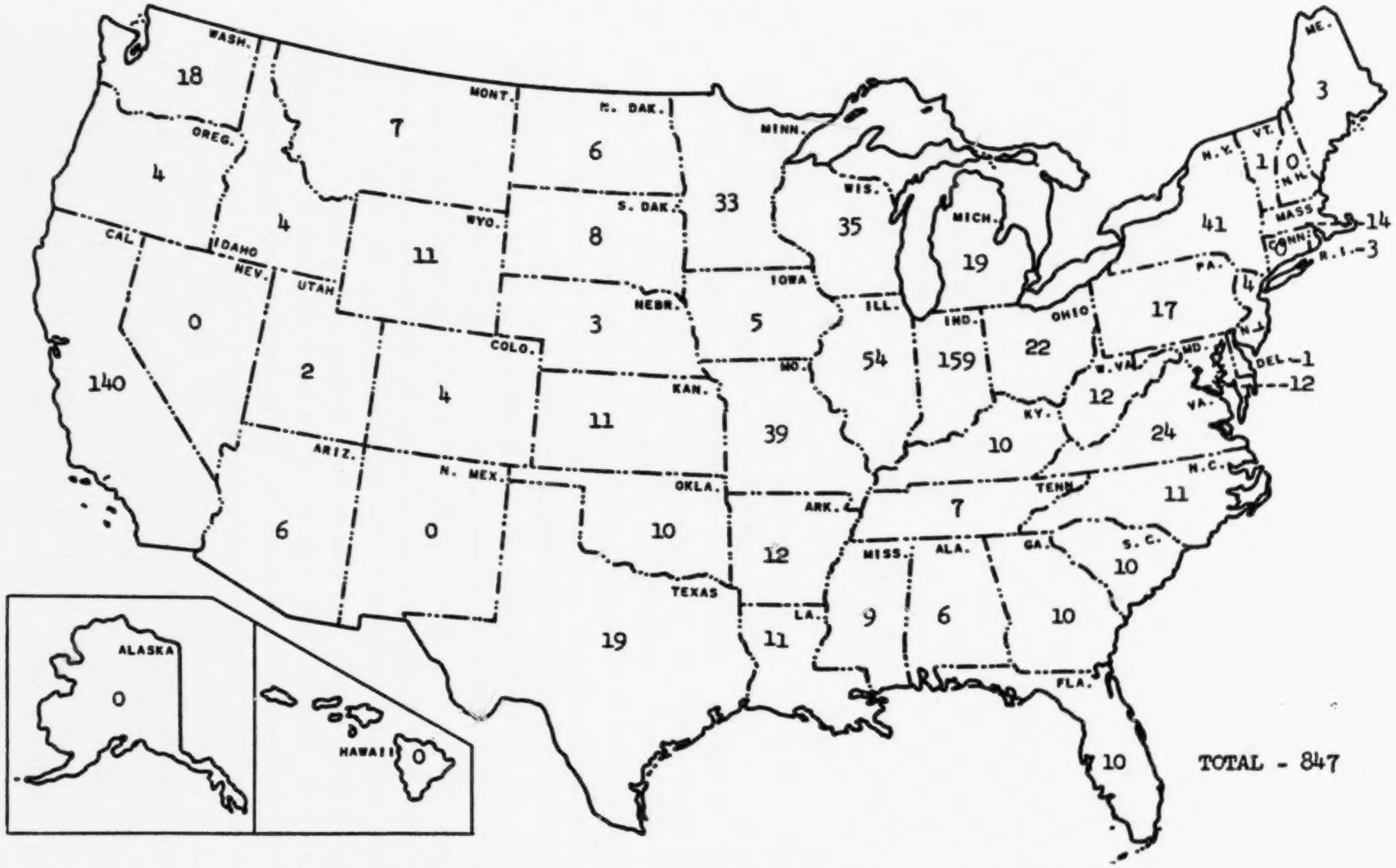
WASH.
18
OREG.
4
CAL.
140
IDAHO
4
NEV.
0
UTAH
2
ARIZ.
6
MONT.
7
WYO.
11
COLO.
4
N. MEX.
0
N. DAK.
6
S. DAK.
8
NEBR.
3
KAN.
11
OKLA.
10
TEXAS
19
MINN.
33
IOWA
5
MO.
39
ARK.
12
LA.
11
WIS.
35
ILL.
54
MISS.
9
MICH.
19
IND.
159
KY.
10
TENN.
7
ALA.
6
OHIO
22
W. VA.
12
GA.
10
FLA.
10
PA.
17
VA.
24
N.C.
11
S.C.
10
N.Y.
41
VT.
1
N.H.
0
ME.
3
MASS.
14
CONN.
0
R.I.
3
N.J.
4
MD.
12
DEL.
1
ALASKA
0
HAWAII
0
TOTAL - 847

Figure 70. Reported stabilization ponds used by industry in the United States—1962.

other wastes were: canning, 104; paper, 105; chemicals, 157; and textiles, 165. The last three were based on limited data and may not be reliable.

Loadings for anaerobic treatment were generally much greater; there was indication that sewage loadings exceeding 250 pounds BOD per acre per day would bring about anaerobic conditions. The review of industrial practices indicates that loadings generally exceeded 160 pounds per acre per day for anaerobic operations. Reported median anaerobic loadings were: canning, 392 pounds BOD per acre per day; meat and poultry, 1,260; paper, 347; textile, 1,433; and sugar, 240.

The fungi and yeasts were examined during a 1-year study of the Lebanon, Ohio, stabilization ponds (Cooke, 1962; Cooke and Matsuura, 1963). More than 100 species of filamentous fungi, including 9 species of *Fusarium* and nearly 50 species of yeasts, were isolated from the ponds. It appeared that several species of fungi potentially pathogenic to plants might occur. Six species of yeasts isolated from the ponds appeared indicative of organic enrichment of water and soil. Cooke stated that effluents from a pond system can readily carry spores from place to place. In the drier areas, effluents from such ponds may be developed as irrigation supplements; thus, heavier than normal spore load is applied to the soil, the effects of which can only be anticipated.

Photosynthesis has been termed the most important single factor in determining the course and effectiveness of stabilization pond treatment. Algae are an integral part of photosynthesis. A striking similarity exists among algal speciation in stabilization ponds. Principal algae (fig. 71) cited as inhbitants of stabilization ponds, include *Chlorella, Scenedesmus, Chlamydomonas* and *Euglena.* Allen (1955) found that algae can be used as a means of following pond operation in California since *Chlorella* and *Scenedesmus* predominate when sewage is undergoing active decomposition, and *Chlorella* is succeeded by *Scenedesmus* and *Chlamydomonas* when oxidation is well advanced. Some of the highest algal densities in California were observed during December and January. The coming of heavy rains with dilution and rise of water levels created a sharp drop in the algal population. Parker (1962) found high algal populations in unicellular aerobic ponds, but much more variety and a lower population level in multicell ponds. Through the use of multicell ponds it was possible to obtain relatively clear effluents free from objectionable algal turbidity.

Maximum total counts of phytoplankton per milliliter have been recorded at 2,800,000 (Neel et al., 1961), 4,700,000 (Mackenthun and McNabb, 1959), and 1,300,000 (Merz et al., 1957). Algal mass, in p.p.m. per volume, has averaged 2,000 to 7,000 with a maximum of 34,700 in Missouri (Neel et al., 1961) and 50 to 250 in Wisconsin (Mackenthun and McNabb, 1959). As related by Fitzgerald and Rohlich (1958), Meffert (1955) reported algal yields of 11 to 16 tons per acre per year during warm weather and 7 tons per acre per year during cool, cloudy weather; average yields of 30 to 35 tons of dry algae per acre per

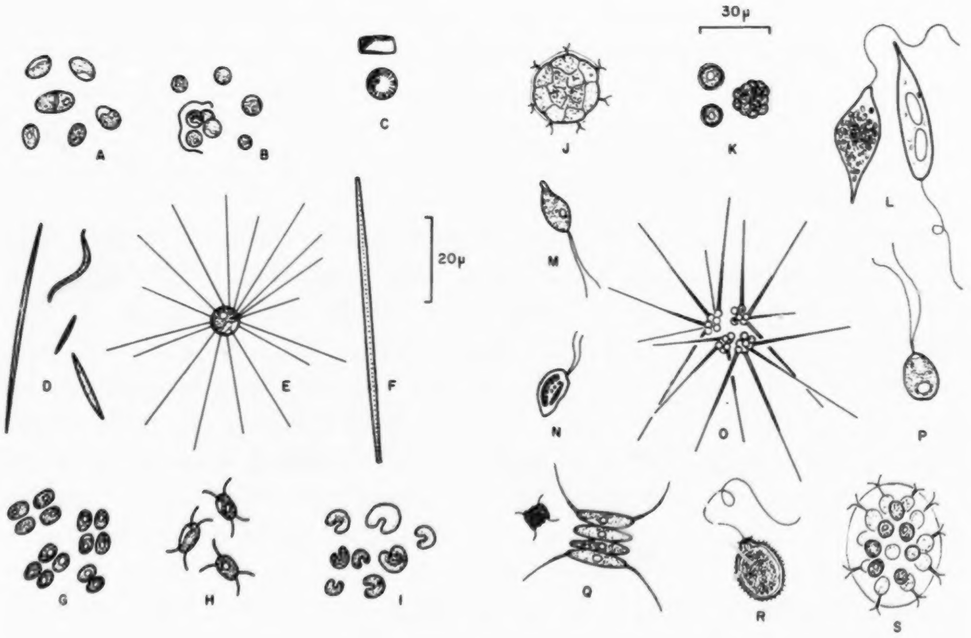

Figure 71. Algae commonly found in sewage waste stabilization ponds. A, *Chlorella ellipsoidea*; B, *Chlorella vulgaris*; C, *Cyclotella operculata*; D, *Ankistrodesmus* spp.; E, *Golenkinia radiata*; F, *Nitzschia palea*; G, *Crucigenia rectanularis*; H, *Chodatella guadriseta*; I, *Selanastrum minutum*; J, *Pandorina morum*; K, *Coelastrum microporum*; L, *Euglena* spp.; M, *Chlorogonium euchlorum*; N, *Cryptomonas erosa*; O, *Micractinium pusillum*; P, *Chlamydomonas* sp; Q, *Scenedesmus* spp.; R, *Trachelomonas* sp.; S, *Eudorina elegans*.

year were obtained from ponds at Richmond, Calif., with rate yields of 60 to 75 tons per acre per year in July and August (Gotaas and Oswald, 1955). Algal yields of 600 to 1,600 pounds per million gallons of sewage have also been reported (Gotaas et al., 1954).

Neel et al. (1961) noted that blue-green algal mats consisting principally of *Oscillatoria* and *Phormidium* developed on detached benthic algae, and created pigpen odors detectable for 20 to 50 feet. Wind would not break up the mats. Loadings in excess of 60 pounds of BOD per acre per day maintained dense plankton populations that probably deprive bottom growths of needed light. Odor nuisances arising from blue-green algal scums have occurred in Alabama, Mississippi, and other southern States. Additional effort needs to be expended to find a solution to this problem.

Bottom organisms in a northern Wisconsin stabilization pond (Mackenthun and McNabb, 1959) were confined principally to three species of midges whose combined population ranged from 36 per square foot in the early spring to 956 per square foot in late fall. There was a 94-percent population reduction caused by anaerobic benthic conditions during the first winter of operation. This benthic population undoubtedly had an impact on the nutrient cycle. Larvae that assimilate nutrients indirectly through feeding on phytoplankton, and subsequently pupate and develop into adults, may completely remove their share of nutrients from the pond. Those killed by winter anaerobic conditions delay the entrance of their share of nutrients into the superimposed water until late winter or early spring. Final effluent polishing might be accomplished by additional ponds in series, the last one containing fish that could be harvested at periodic intervals.

Mosquitoes in stabilization ponds have usually been associated with growths of aquatic vegetation (Beadle and Harmston, 1958; Myklebust and Harmston, 1962; Beadle and Rowe, 1960; Mallack et al., 1962). Shallow ponds with abundant vegetation produce mosquito problems; ponds free from vegetation have presented no problem. Suggestions for minimizing mosquito problems include specifications on bank slope, depth, the clearing of the pond bottom prior to filling, a system of water level control to permit the use of soil sterilants to control marginal vegetation, and the use of larvicides such as diesel oil, DDT, and malathion to control significant mosquito production in the event of failure of other remedial measures. The use of specific herbicides or larvicides is dependent on local pond conditions and the ultimate fate of effluent water.

Kimerle and Enns (1968) reported that 60 species of aquatic insects were found in 18 central Missouri stabilization ponds. Three species of midges predominated. *Culex pipiens* and *C. tarsalis* bred in pond outlets where overlfow water was allowed to drain across a flat area before reaching a drainage ditch.

In the Wisconsin stabilization pond studies, phytoplankton counts were recorded as the number of organisms per ml., as well as the volume of cell mass in p.p.m. (fig. 72). The dissimilar trends between the two approaches of arriving at the plankton standing crop, and the similarity of phytoplankton volumetric data between the two stabilization ponds illustrate the necessity of "going the extra mile" to obtain volumetric data. Both stabilization ponds were receiving biochemical oxygen demand (BOD) loadings of 20 to 23 pounds per acre per day.

Local climatological conditions influence to a great extent the functioning of a stabilization pond. Under the severe winters of northern Wisconsin, where ice and snow cover the pond's surface, unsatisfactory waste stabilization occurred at loadings of 20 pounds and above of BOD (fig. 73). Satisfactory pond operation occurred during summer and fall.

The operation of a stabilization pond requires frequent inspection and periodic maintenance to be reasonably free from odors. Under certain operational and climatic conditions blue-green algae may appear as a substantial floating mass within a period of 2 or 3 days that can be wind congregated along the leeward shore. Under a hot sun, the surface of the algal mass will bake, decompose, and emit pungent odors. Specific causes of algal mat formation cannot be stated specifically, and operational and climatic factors may indeed interact to create the problem.

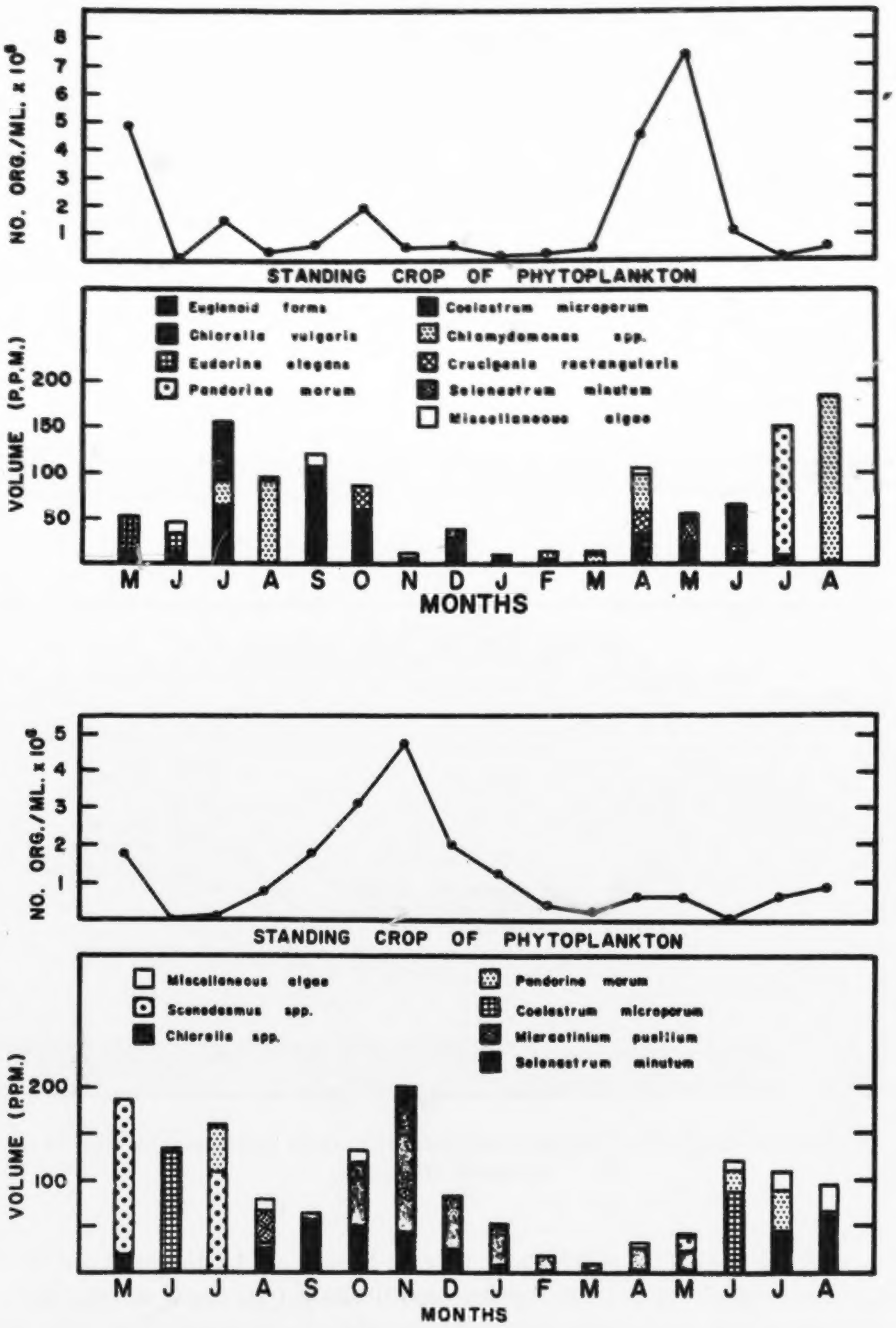

Figure 72. Phytoplankton standing crops in Wisconsin stabilization ponds May 1957, to August 1958, reported as No./ml. and as p.p.m. by volume.

Three avenues of approach are available to combat odors arising from floating blue-green algal and other solids on stabilization ponds: (1) Floating solids may be skimmed off and buried whenever they appear, or

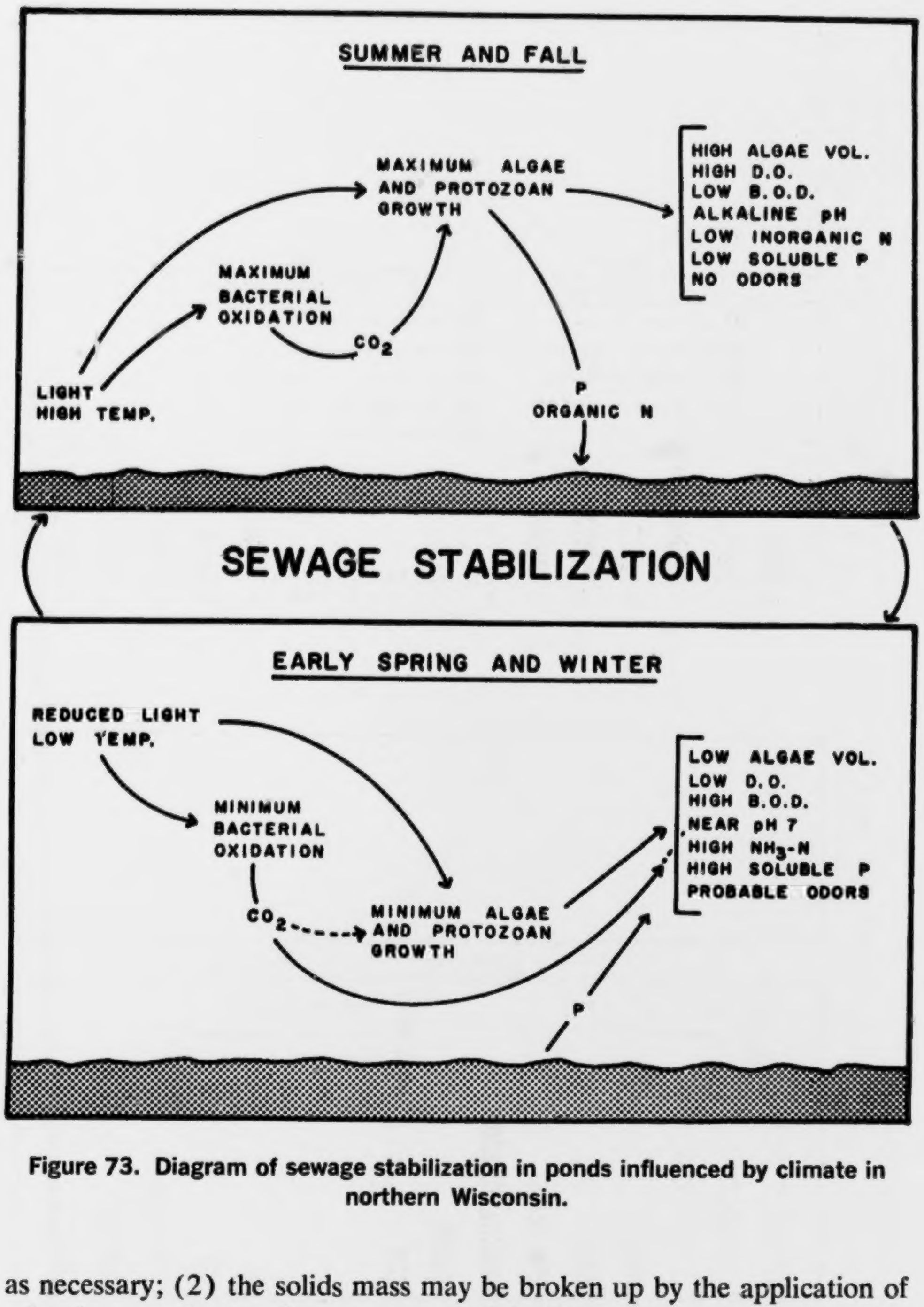
SUMMER AND FALL
MAXIMUM ALGAE AND PROTOZOAN GROWTH
HIGH ALGAE VOL.
HIGH D.O.
LOW B.O.D.
ALKALINE pH
LOW INORGANIC N
LOW SOLUBLE P
NO ODORS
MAXIMUM BACTERIAL OXIDATION
CO2
LIGHT
HIGH TEMP.
P
ORGANIC N
SEWAGE STABILIZATION
EARLY SPRING AND WINTER
REDUCED LIGHT
LOW TEMP.
LOW ALGAE VOL.
LOW D.O.
HIGH B.O.D.
NEAR pH 7
HIGH NH3-N
HIGH SOLUBLE P
PROBABLE ODORS
MINIMUM BACTERIAL OXIDATION
CO2
MINIMUM ALGAE AND PROTOZOAN GROWTH
P

Figure 73. Diagram of sewage stabilization in ponds influenced by climate in northern Wisconsin.

as necessary; (2) the solids mass may be broken up by the application of a hard spray of water from a pump and firehose type spray nozzle, or by running a boat with outboard motor through the nuisance area; (3) the formation of the floating algal mass may be controlled through the periodic use of an algal-killing chemical such as copper sulfate. Users of chemical controls have indicated that blue-green algae may be killed by copper sulfate, but that green algae are not injured sufficiently to handicap the stabilization or organic wastes. In treating a stabilization pond with copper sulfate, the commercial grade crystals are placed in a burlap bag, and this, in turn, is towed in the water behind a boat as it is propelled back and forth across the pond until the crystals dissolve, and the pond is treated completely.

The copper sulfate dosage rate is based on the total methyl-orange alkalinity of the water. With a methyl orange alkalinity of less than 50 mg./l, a calculated dosage of 0.5 p.p.m. commercial copper sulfate is used; with higher alkalinities, 1 p.p.m. copper sulfate is used. Thus, for a high alkalinity pond that is 4 feet deep, 10 pounds of commercial copper sulfate per acre is required. Application might be necessary as often as every two weeks depending on pond conditions. The pond should be observed closely following such a treatment to ascertain that the purpose for which the pond was initially designed is not seriously impaired. Chemical application will have no advantage when applied to an area that already has substantial floating solids. These solids must be removed and buried, or dispersed prior to treatment, because they will continue to emit odors.

14

SLIMES

UPON the introduction of waste nutritive materials into water courses, biological slimes may develop to the extent that visible masses appear (fig. 74). These are woolly coatings on submerged objects or tufts and strands, sometimes 15 inches or more long, streaming in the current from point of attachment. They vary in color from milky white in fresh new growth to dull grey-white, brown or rusty-red, depending on age, nutrition, and type and amount of solids they entrap from the passing water. In many cases, a rather heterogenous population makes up what is commonly called the slime floc. For example, Tiegs (1938) described the "sewage fungus" * community as including the following organisms: *Sphaerotilus natans, Beggiotoa alba, Thiothrix nivea, Fusarium aquaeductum, Leptomitus lacteus* and *Mueor* sp. The two organisms that have been described repeatedly as ecologically dominant are *Sphaerotilus natans* and *Leptomitus lacteus*. Butcher's (1932) description of his "sewage fungus" community also included the fungus *Shenospora* and the protozoan *Carchesium.*

Numerous problems arise from the presence of slime growths in streams. Where commercial or game fishing exists, drifting *Sphaerotilus* may foul gill nets rendering them ineffective (Lincoln and Foster, 1943**; Ingram and Towne, 1960; Wilson et al., 1960), interfere with fish hatching by coating fish eggs, and smother aquatic fauna that serve as food for fish. Biological slimes and the materials they entrap, such as plant fibers, wood chips, and debris, blanket the streambed and destroy the homes of

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* *Sphaerotilus* is not a genus of a fungus, but is a filamentous bacterium; for years in the literature of sanitary science it has been referred to incorrectly as a fungus.

** Lincoln, J. H. and R. F. Foster, 1943. Report on the Investigation of Pollution in the Lower Columbia River. Washington State Pollution Commission and the Oregon State Sanitary Authority.

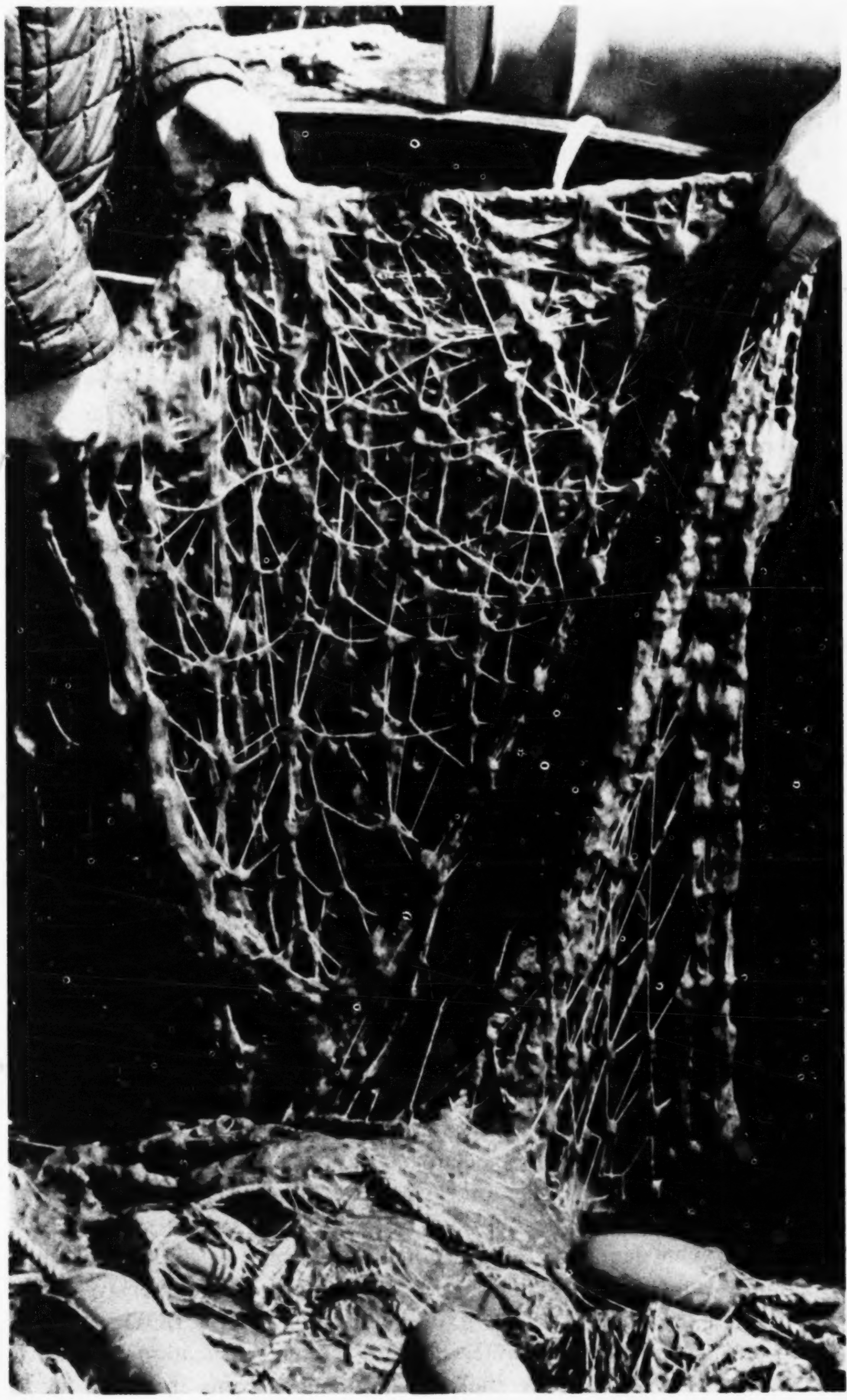

Figure 74. Massive Slime Accumulation on Commercial Fisherman's Net (Photo by; Horn Photo Clatskanie, Oregon, May 6, 1964)

clean water associated organisms. Because organic food is usually abundant where slime growths occur, pollution tolerant organisms such as sludgeworms may become abundant in association with slime growths. These organisms do not offer the fishfood potential that clean water associated species do. Conditions may become so severe that all benthos are eliminated.

Kramer and Smith (1965) found that suspended conifer groundwood fibers had no effect upon egg survival, respiration rate of embryos, or growth rates of alevins and juveniles from eggs incubated in fiber but hatched and grown in clean water. When alevins were held in woodfiber suspensions, survival was reduced from 98 to 100 percent in controls to 0 to 72 percent in 250-p.p.m. fiber. Walleye (*Stizostedion vitreum vitreum*) eggs were incubated in a temporary jar hatchery using Rainy River water taken downstream from paper mills discharging sulfite, kraft, insulating board, and groundwood wastes (Smith and Kramer, 1963). Eggs were also incubated in trays held on and off the bottom in the river downstream from the mills, upstream from the mills, and in tributary streams. In two years, survival of eggs in jar controls was 31.2 to 73.5 percent. Survival to hatching of eggs jar-incubated in polluted water was 0.02 to 6.0 percent. At river stations downstream from the mills, survival of tray eggs on the bottom did not exceed 1.2 percent; and offbottom, 3.5 percent. Eggs held on the bottom upstream from the mills had maximum survivals of 37.6 percent; and off the bottom, 49.1 percent. In most experiments in polluted Rainy River water the principal cause of mortality was *Sphaerotilus* growths on the eggs, which prevented successful emergence of fry. Prior to hatching, egg survival rates in jars were similar in controls and in experiments. Chemical treatment to remove slime increased the hatch of eggs. *Sphaerotilus*-covered eggs removed to fresh water lost the bacterium and hatched at a high rate.

Biological slimes bring about an aesthetically unpleasant stream. To the public, they are an obvious sign of stream pollution (fig. 75). Prolific slime growths destroy the recreational potential of the water, thus interfering with one of the major public-associated uses of water.

Because most bacteria respond directly to the introduction of organic materials to the water course, they may be considered the major factor in the self-purification processes occurring in most natural waters. Slime growths in natural waters function similarly to those in treatment plants in the stabilization of organic materials. In simulated stream studies, biochemical oxygen demand (BOD) reductions as high as 87 percent were obtained at waste retentions as low as 33 minutes after extensive slime growths had developed. In one experiment, 11.5 mg./l BOD were removed during this short time interval. Similar high purification rates have also been observed in many shallow, turbulent streams in which slime growths were the major force in the self-purification process (Amberg and Cormack, 1960).

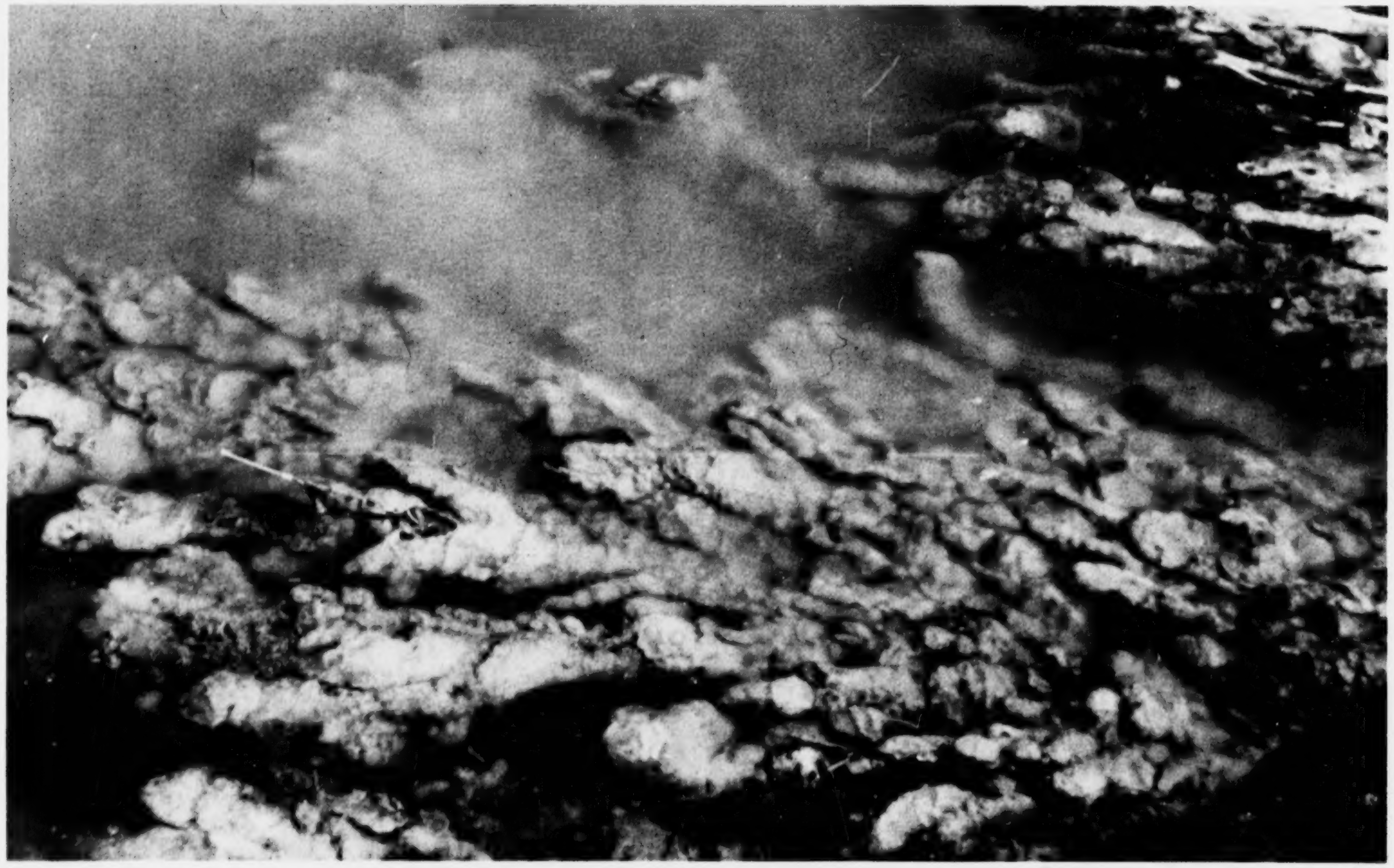

Figure 75. Slimes from waving masses in polluted streams that destroy the habitat for animals, as well as the aesthetics of the waterway.

Sphaerotilus

Dondero (1961) cited a number of quantitative measurements that have been made on *Sphaerotilus* infestation of streams. Although the productivity of polluted streams is difficult to estimate, some measurements on detached masses of floating *Sphaerotilus* have been made from which the amount of material passing the river cross section has been calculated, for example: (*a*) in the Danube and Main Rivers, about 46 tons wet weight per day of drifting *Sphaerotilus* (Demoll and Liebmann, 1952); (*b*) in the Main 325 tons, wet weight per day (Liebmann, 1953); and (*c*) in the Oker River, 12.5-100 gm. dry weight per cubic meter of water (Popp and Bahr, 1954). By using the factor 7 percent (Popp and Bahr, 1954; Liebmann, 1953, used 8 percent), the wet weight values can be converted to 4.5 and 22.7 tons dry weight, respectively. Such values indicate the potential for the deposition of large amounts of decomposing *Sphaerotilus*. Popp and Bahr (1954) measured deposition in layers 1 to 2 meters thick in areas of high oxygen deficiency. There was a high degree of secondary pollution resulting from the decomposition of the *Sphaerotilus* sludge for months after heavy pollution with sugar waste. The oxygen demand of dead *Sphaerotilus* sludge was about 11 times that of the same amount of living *Sphaerotilus*.

The filamentous sewage bacterium, *Sphaerotilus natans,* has been implicated in the bulking of activated sludge (Lackey and Wattie, 1940). Ruchhoft and Kachmar (1941) concluded that *Sphaerotilus* was a delicate indicator of disturbances of the biological equilibrium of activated sludge but not a primary cause of bulking. It has been found in paper machine wet felts, and clogging of the felts with *Sphaerotilus* was experimentally produced (Drescher, 1957). It has created problems by clogging intake screens and cooling water lines in powerplants.

The secondary effects of biological slimes in streams may be even more serious (fig. 76). The stream slime community is composed of a variety of microorganisms that are held together as a mat principally by *Sphaerotilus*. Such interwoven mats entrap silt, sand, fibers, and chips. The filamentous masses offer shelter and support for other organisms such as bacteria, protozoans, nematodes, rotifers, and occasionally midge larvae. During the process of decomposition, or because of physical disturbances, mats sometimes as large as 3-feet in diameter "boil" to the water's surface in an unsightly foul-smelling eruption. These "boils" may settle at or near the point of origin or be carried downstream to areas where the flow velocity permits settling. Here sludge banks are formed that give rise to anaerobic conditions with subsequent offensive effects. These sludge banks may be formed many miles downstream from the initiating pollution source, thus increasing the stream reach of pollution.

There were at least 3 kinds of slime or biological masses affecting gill nets in the Columbia River *: (*a*) slimes composed mostly of wood fib-

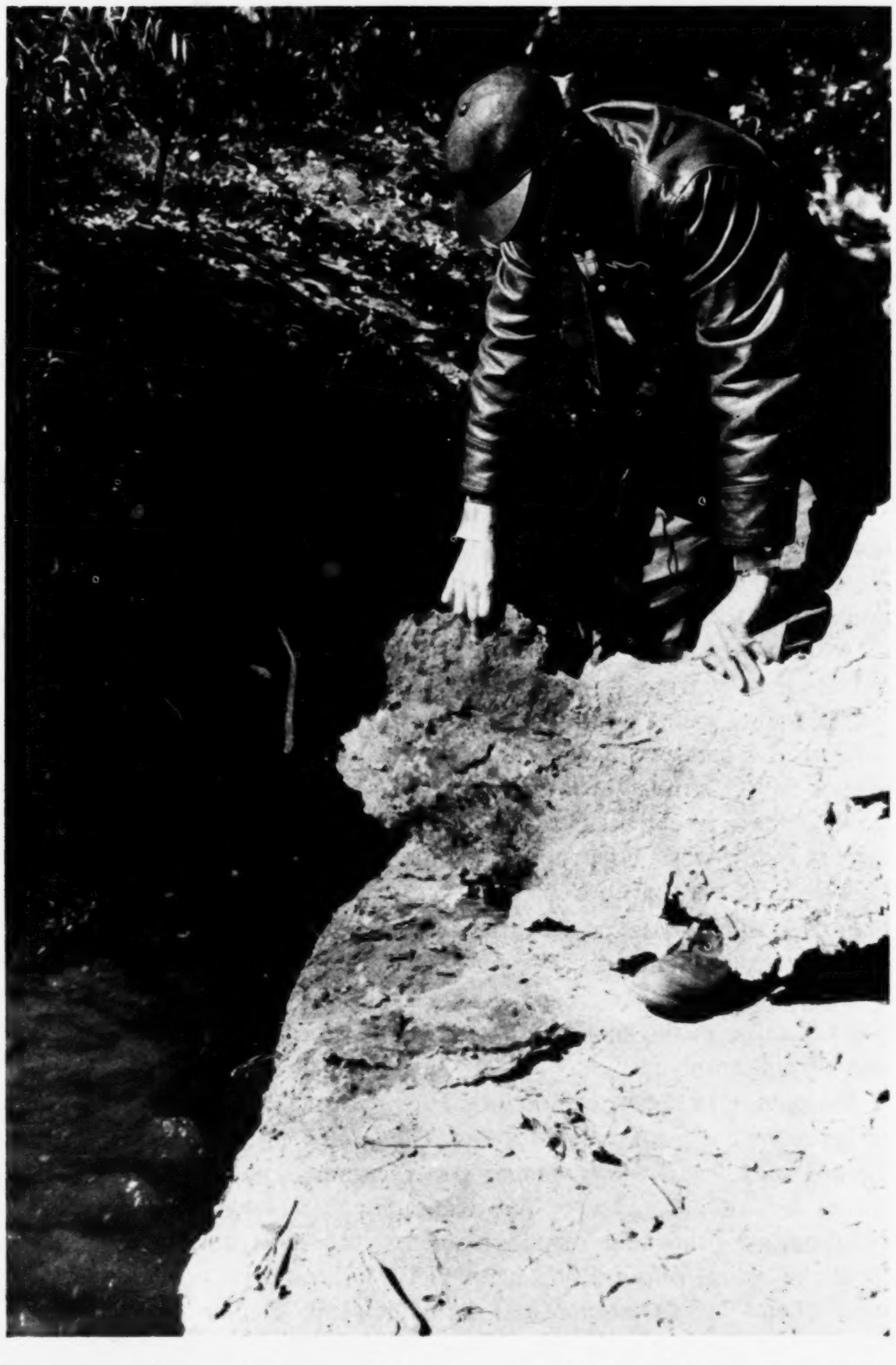

Figure 76. Dried wastes from pulp and paper-making operations. These fibers are often held together by *Sphaerotilus* and other slimes, forming a blanket over the streambed.

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* A report, Pollution of Interstate Waters of the Lower Columbia River, U.S. Department of Health, Education, and Welfare, Water Supply and Pollution Control Program, Region IX, Portland, Oreg., August 1965.

ers, stuck together by *Sphaerotilus,* which is very difficult to remove from nets when wet and nearly impossible to remove when dry because it hardens to a substance resembling plastic wood; (*b*) biological masses, principally plant trash and leaf and grass fragments, which adhere to nets when wet, but crumble away when dry; (*c*) masses composed almost entirely of *Sphaerotilus.*

The appearance of *Sphaerotilus* in streams as the dominant organism has repeatedly been correlated with the entry of industrial wastes (Harrison and Heukelekian, 1958). Butcher (1932) stated that it is associated with effluents from the following industries: beet sugar, paper, rayon, glue, and flour mills. Other observers have noted its occurence following waste discharges such as textile bleach, byproduct coke, dairy wastes, and spent sulfite liquors. Wuhrmann (1949) asserted that the organism does not grow in undiluted sewage. DeMartini (1934) reported the organism in sewers carrying very dilute sewage, and Agersborg and Hatfield (1929) noted that it was present in raw sewage, Imhoff tanks, and aeration tanks. Amberg and Cormack (1960) stated that *Sphaerotilus* grew on kraft effluents as well as on spent sulfite liquor. No slime growth was obtained from the kraft bleach plant effluents. They stated further that slime growths may be expected in discharges of weak wash waters and evaporator condensate from evaporation and burning of spent sulphite liquor. Amberg and Cormack cited Scheuring and Höhnl (1956) to the effect that *Sphaerotilus natans* will grow at sulphite waste liquor dilutions of 1:700, 000 or at BOD levels in the range of 0.05 to 0.10 mg./l. The ability of slime growths to extract nutrients from large volumes of flowing water at extremely low waste concentrations presents a difficult problem in obtaining adequate control.

Sphaerotilus can assume a variety of different appearances that are correlated with different nutrient conditions. The organisms giving rise to the Sphaerotilus slime growths must be present in the flowing stream at all times because of the sudden appearance of slimes following the introduction of pollution.

Naumann (1933) was quoted by Harrison and Heukelekian (1958) as early investigatng the possbility of *Cladothrix dichotoma* being transformed into *Sphaerotilus natans* under certain conditions. These organisms are similar, except that *Cladothrx dichotoma* exhibits regular dichotomous branching of the filaments and does not have the slimy sheath of *Sphaerotilus.* Pringsheim (1949) showed that *Sphaerotilus natans, Cladothirx dichotoma,* and the ecologically distinct *Leptothrix ochracea* could give rise to similar cultures by appropriate treatments.

FACTORS THAT STIMULATE SPHAEROTILUS GROWTHS

Under laboratory conditions the most important food requirements necessary for heavy growth were sugars and organic nitrogen (Lackey and Wattie, 1940). These authors and others (Ruchhoft and Kachmar, 1941) described a cultur[illegible]ethod with a medium that was found to contain ample quantities of a[illegible]he nutrient materials for the growth of *Sphaerotilus natans*. This mediu[illegible] contained the following materials:

	Mg
Dextrose	1,000
Peptone	600
Meat extract	200
Urea	50
Na_2HPO_4	50
NaCl	15
$CaCl_2$	7
$MgSO_4$	5
KCl	7
Distilled water to make 1 liter	

The media was sterilized, seeded with *Sphaerotilus* and aerated continuously through a ball diffuser. Growth occurred in 24 hours.

There is general agreement that the luxurious growths similar to those found under stream conditions cannot be reproduced in the laboratory with inorganic sources of nitrogen. There are many references in the literature to the necessity of a supply of amino acids by *Sphaerotilus*. The organism does not require accessory growth factors such as vitamins (Wuhrmann and Koestler, 1950). Harrison and Heukelekian (1958) stated that cultural experiments showed growth of *Sphaerotilus* when nitrate is the nitrogen supply. There was evidence that the utilization of ammonium compounds depended on the carbon supply. For luxurious growth, an organic nitrogen supply was necessary. A wide variety of organic compounds can serve as carbon sources for *Sphaerotilus;* these include mono- and di-saccharides, organic acids, alcohols, and amino acids.

Höhnl (1955) concluded that visible *Sphaerotilus* growths do not occur as long as the pH is below 5.5. A pH of 6 to 7 is favorable for growth. Optimum temperature is 10 to 15° C. Amberg and Cormack (1960) observed excellent slime growths in the Columbia River where stream velocities ranged from 0.4 to 2.0 feet per second. Increases in velocity at constant concentrations increase the amount of food passing a unit growing surface. These authors stress the importance of both phosphorus and nitrogen for optimum growth. Working on the Columbia River, they observed active competition between filamentous and planktonic algae and *Sphaerotilus* for available phosphorus.

Phaup and Gannon (1967) described ecological investigations in an experimental outdoor channel receiving beet sugar or crude molasses. *Sphaerotilus*-dominated biological flocs were stimulated to bloom proportions within 30 hours after the addition of as little as 1 mg./l sucrose. Maximum growth was obtained at a concentration of 5 mg./l sucrose at velocities from 0.58 to 1.49 ft./sec. in the temperature range of 20 to 28° C. after 72 hours of feeding. Under these conditions, detached and floating materials were equivalent to new material being formed. Maximum growth and classical *Sphaerotilus* flocs could not be obtained at temperatures below 17° C.

Ormerod et al. (1966), in working also with outdoor channels, found that additions of calcium-base spent sulphite liquor caused massive growths of a community dominated by *Sphaerotilus natans,* with a pink filamentous organism frequently epiphytic on the *Sphaerotilus.* When the temperature fell below 10° C., *Leptomitus lacteus* appeared among the growths of *Sphaerotilus* and the pink organism grew epiphytically on both.

Sphaerotilus Control

Lackey and Wattie (1940) tested substances for toxicity for *Sphaerotilus* in activated sludge or in cultures and found that the following were toxic at the doses indicated (mg./l): chlorine (0.5 residual), silver nitrate (0.5–2.0), phenol (5.0), acetic acid (50), brilliant green (5.0), malachite green (5.0), Janus green (20), methylene blue (20), and gentian violet (10). Chlorine was considered to be the most feasible substance for large scale use, as in water and sewage treatment plants.

In water treatment plants, high initial doses of chlorine are required to remove establised slimes. Repeated dosing to 50 to 100 mg./l residual chlorine followed by high-pressure air and flushing has been used (Alexander, 1944). After dislodgment of the slimes, 0.75 to 1.0 mg./l residual chlorine was maintained in the effluent water. DeMartini (1934) recommended 2 mg./l in wastes for *Sphaerotilus* control in sewers.

Amberg and Cormack (1960) found, in laboratory studies, that intermittent discharge of spent sulphite liquor for 24 hours followed by 5 days of storage was very effective in reducing slime growth by more than 80 percent. Field studies showed that by discharging 24 hours every 6 days, growth was lower than growth obtained from ⅕ the total liquor discharged continuously.

Sphaerotilus infestations were controlled downstream from a southern Kraft pulp mill by retaining all black liquor from entering the river during optimum conditions for slime growth. The liquor was held for a period of 5 to 6 days and released over a 1- to 2-day period, which was insufficient time for an infestation to materialize (McKeown, 1962).

Leptomitus

Leptomitus lacteus is a member of the most abundant order of aquatic fungi, the Saprolegniales. No cells are visible in the organism, although characteristic constrictions give it a pseudoseptate appearance. The constrictions are a result of the presence of cellulin plugs, whose function is unknown. Harrison and Heukelekian (1958) state that *Leptomitus* requires high molecular weight compounds of nitrogen to supply its needs for this element. Schade (1940) has confirmed that no growth occurs with ammonium, nitrate, or nitrite compounds, even in the presence of available carbon compounds. The optimum pH for luxuriant growth is 5.4 to 6.0 and the suitable pH range is 4.3 to 7.5; it can exist below pH 2.5.

Fouling Bacteria

Iron bacteria are typically aerobic organisms, widely distributed in nature, and commonly observed in most habitats. Generally they are considered fouling organisms and not agents of corrosion, but they may indirectly contribute to the latter. Energy is derived from the oxidation of ferrous iron to the ferric state and in the process, ferric hydrate is precipitated. The iron withdrawn from the water is deposited in the form of hydrated ferric hydroxide on or in the mucilaginous sheaths of the organism. These processes produce a large amount of brown slime and may impart a reddish tinge and an unpleasant odor to water.

The occurrence of iron bacteria was observed in northern Wisconsin drainage waters in which deposits had accumulated to a depth of 2 feet throughout several miles of drainage ditch. Control was effected with 3-p.p.m. copper sulfate application. Springs often have reddish-brown deposits produced by the activity of iron bacteria, and stagnant marshes may produce a reddish scum resulting from this activity. As early as the middle of the nineteenth century, iron bacteria in potable water supplies were reported to be the causative organisms of taste and odor problems, and the condition was called a "water calamity."

Starkey (1945) reviews the transformation of iron by bacteria in water and states that iron bacteria are some of the most important fouling organisms because they not only produce troublesome accumulations of cell material but also produce still greater quantities of ferric hydrate. In addition to the iron bacteria there are various other bacteria, including sulfur bacteria and sulfate-reducing bacteria, which are responsible for various transformations of iron. Some bring iron into solution, others cause its precipitation and some are responsible for corrosion.

Some of the sulfur bacteria are encountered occassionally in water, particularly in water containing sulfide or elemental sulfur. One of the typical sulfur bacteria, *Thiobacillus thiooxidans,* may bring large amounts of iron into solution under conditions favorable for its development. It is an aerobic bacterium that has the capacity to oxidize sulfur, and has been linked to the corrosion of iron pipelines.

Sulfate-reducing bacteria are of importance in water distribution systems because they produce sulfide which is dissolved in the water and makes the water objectionable by reason of the odor, the presence of suspended black particles, and the corrosive effect of the sulfide on steel and other metals. In cases where the water in iron pipes and concrete conduits contains sulfide or where sulfide is produced as in sewage, and the pipe is only partly filled so that there is an air blanket over the water, some of the sulfide becomes dissolved in the moisture film on the upper walls of the pipe. Here it undergoes oxidation, caused principally by sulfur bacteria, and the sulfuric acid that is formed attacks the pipe, causing its disintegration (Starkey, 1945).

Alexander (1944) stresses that in controlling slime-forming iron and sulfur organisms in a water supply, control is only partly attained when the plant effluent is made sterile. It is equally important to clean up and maintain a distribution system free from iron and sulfur organisms, a system in which chlorine residuals will be carried to the remotest part of the distribution system.

15

NUISANCE ORGANISMS

APART from the investigation of water pollution problems, waterworks infestations, or waste treatment characterizations, the aquatic biologist is often called upon to consult on nuisance aquatic organisms, and to proffer recommendations for their control. Nuisance organisms may be either plant or animal, and there are many varieties of each.

Plant nuisances may curtail or eliminate bathing, boating, water skiing, and sometimes fishing; perpetrate psychosomatic illness in man by emitting vile stenches; impart tastes and odors to water supplies; shorten filter runs or otherwise hamper industrial and municipal water treatment; impair areas of picturesque beauty; reduce or restrict resort trade; lower water front property values; interfere with the manufacture of a product in industry, such as paper; on occasion become toxic to certain warm-blooded animals that ingest the water; foul irrigation siphon tubes and trashracks; and cause skin rashes and hay-fever-like symptoms in man. These plant nuisances may be grouped into the algae and the higher aquatic plants. Algae appear as floating scums; suspended matter giving rise to murky, turbid water or water having a "pea soup" appearance; attached filaments; and bottom dwelling types that may be confused with the rooted higher aquatic plants. The higher aquatic plants grow submersed, floating, or emersed.

When aquatic animals become excessively abundant, they become pests and nuisances to man because of their biting habits and their sheer mass of numbers. Some aquatic animals serve as intermediate hosts for parasites that may attack man directly and some serve as vectors of diseases that affect the health of man. Animal congregations often cause hydraulic problems in water transport systems.

Algae

Most algal problems occur when growth conditions permit the formation of a "bloom." A bloom is an unusually large number of cells (usually one or a few species) per unit of surface water, which often can be discerned visually by the green, blue-green, brown or even brilliant red discoloration of the water. Lackey (1949) arbitrarily defined a bloom as 500 individuals per ml. of raw water. He found bloom conditions 509 times during a 2-year survey of 16 southeastern Wisconsin lakes and of 3 rivers in 1942–43. Of this number, only 13 percent were blue-green algae, generally the most troublesome nuisance-producing group. Diatoms are rarely obnoxious except in water supplies; they predominated in 40 percent of the blooms. The lake with the highest concentration of inorganic nitrogen (N) and inorganic phosphorus (P), 0.79 and 0.38 mg./l respectively, had the most blooms—112 during the 2-year period.

Algae are found in every non-toxic aquatic habitat. Constituting a primary source of food for fish and other aquatic animals, they may be free-floating and free-swimming, or attached to the bottom substratum.

There are some 1,500 genera and 17,400 species of algae, according to Fuller and Tippo (1954). Fresh-water algae fall into major groups including (a) blue-green algae; (b) green algae; (c) yellow-green algae; (d) golden-brown algae and diatoms; (e) red algae; (f) euglenoids and (g) dinoflagellates.

The blue-green algae (Cyanophyta) are extremely primitive in several respects. The plant body is a single cell; colonies may be formed that are loose aggregations of similar cells among which there is little or no differentiation. Their nuclear material is not organized into a definite nucleus, but is scattered throughout the center of the cell. Green chlorophyll is not localized in definitely formed bodies, but is diffused throughout the peripheral portion of the cell. In addition to the green chlorophyll there is a blue pigment and sometimes a red pigment. Reproduction is by simple division (fission). Blue-green algae produce "water blooms," "pea soup" appearance, septic "pig-pen" odors; impart a "fish taste"; and cover rocks with slimy gelatinous masses.

Green algae (Chlorophyta) have pigments that are principally chlorophyll confined to chloroplasts or definite bodies. There is an organized nucleus, and the motile cells, either vegetative or reproductive, have flagella.

The yellow-green algae, golden-brown algae, and diatoms (Chrysophta) have the pigment confined to definite bodies. There is a greater proportion of yellow or brown pigment than chlorophyll. The cell wall of the diatoms is composed of silica.

The euglenoids (Euglenophyta) are unicellular, motile, and bear one to four flagella. They have a definite nucleus with grass-green chlorophyll localized in definite chlorophyll bearing bodies (Plastids).

The group of dinoflagellates (Pyrrophyta) includes a great diversity of mostly pigmented and mobile unicellular organisms. Two flagella are present. Brown pigments predominate, although chlorophyll is present.

Excessive algal growths are troublesome in many ways. When present in great numbers, algae may: give an unsightly blue-green or green appearance to the water, form a massive floating scum that obstructs navigation or impairs water use, in decay produce noxious odors that drive people from the area, remove dissolved oxygen from the water when decomposing and kill aquatic life as a result, foul fish harvesting equipment and water intake devices, reduce the carrying capacity of water distrubution systems, and destroy bathing and other water use areas. *Stigeoclonium, Oedogonium, Ulothrix,* and *Cladophora* have been problems in irrigation systems where they have restricted flow in the canals, and fouled pumps and tubes. *Cladophora* has been a problem of great concern in Lakes Ontario, Erie, and Michigan where abundant growths have become detached through wave and wind action to be washed upon a beach where they decompose to make the area uninhabitable.

Blue-green algae have been severe nuisance problems, especially to those engaged in water oriented recreation in most eutrophic lakes. *Chara,* a branched erect alga that becomes encrusted with calcareous deposits giving the plant a rough surface, has become a problem in many high alkalinity lakes and ponds. Often *Chara* becomes abundant following the destruction of aquatic vascular plants. Should the lake or pond bed be composed of a peat-type material, *Chara* can become detached from its mooring and bring substantial quantities of bottom with it when it rolls to the surface in 9-inch thick rafts that obstruct navigation, destroy aquatic aesthetics, and emit vile odors. The author has witnessed dead tree stumps, with root systems that measure 20-feet in diameter, embedded in these floating *Chara* rafts.

In highly enriched streams, green algal streamers that may exceed 50-feet in length provide an excellent substrate for blackfly larvae, midge larvae, and other nuisance animals.

More and more interest is being aroused in the toxic effects of freshwater algae on animals. This interest stems partly from a recent upswing in the number of reported cases of animal poisonings related to algal blooms, and from a growing appreciation of the strictly scientific and biological problems involving the physiology of algae, especially those that produce toxic substances (possibly toxins), antibiotics, and growth-stimulating excretions (Ingram and Prescott, 1954).

Wheeler et al. (1942), stated that no human outbreaks of gastroenteritis have ever been traced to algal contamination of drinking water, and that it is probable that the tastes and odors almost invariably associated with severe algal pollution would cause humans to seek other sources for drinking water before a harmful amount of the polluted water would be consumed. These authors state: "It should be noted that the presence of algae in drinking water, in addition to causing tastes and odors, may have some importance from the standpoint of the allergist as algae may, on occasion, liberate considerable amounts of protein in water. If allergic reactions to algae proteins do occur, they would be as uncommon as they would be obscure and hardly likely to occur as a public health problem."

Schwimmer and Schwimmer (1955) chronologically summated 38 incidents of animal intoxications by phytoplankton from 1878 to 1951. In most cases the attacks occurred after the animals had drunk from lakes or ponds containing heavy algal growths, usually during successive days of hot weather. The reported symptoms of algal intoxications vary but the most striking clinically were the involvements of neuromuscular and respiratory systems in cattle. As aptly described by Francis (1878), "the animals developed stupor and unconsciousness, falling and remaining quiet, as if asleep unless touched, when convulsions came on, with the head and neck drawn back by rigid spasm which subsided before death."

Fitch et al. (1934), observed that when samples of toxic algae were fed in the fresh state to guinea pigs, rabbits, and chickens, death occurred in a very short time. When toxic algae were stored for a brief period at ice box temperature, or dried, it was further observed that it was almost impossible to produce death by feeding, but with a similar dose, animals could be killed quickly by inoculating intraperitoneally. The specific alga or algae used are not listed.

The syndrome of symptoms, described by Fitch et al., exhibited by guinea pigs from the feeding or from the inoculation intraperitoneally of a fatal dose of toxic algae was: (1) restlessness; (2) urination; (3) defecation; (4) deep breathing; (5) weakness in the hind quarters; (6) sneezing; (7) coughing; (8) salivation; (9) lachrymation; (10) clonic spasms and death. In studying experimental deaths of guinea pigs, it was noted that they occasionally show symptoms of intoxication and then recover.

Olson (1952) pointed out that the toxicity of unpurified algal material from field collections varies a great deal. For example, 0.02 ml. injected into mice intraperitoneally may kill a 20-gram individual in an hour, whereas from another sample it may require 2.0 to 3.0 ml to produce death in 18 hours. Certain samples of toxic algae (0.1 ml fatal dose) taken from a lake 1 day kill mice in 20 minutes, whereas 9 days later, samples from the same lake with a greatly increased dosage (2.0 ml) may require 5 hours to produce death.

The poisoning of wild and domestic animals by a toxic waterbloom of *Nostoc rivulare* Kuetz from a pond in central Texas has been described by Davidson (1959). Cattle, fish, frogs, and fowl that drank the water containing a heavy growth of the alga became acutely ill, and many died within a short period of time. Most of the accompanying symptoms were similar to those described for a number of other toxic waterblooms. Intraperitoneal injections of albino mice with fresh algal material or with extracts prepared from preserved material produced symptoms that were uniform. The characteristic symptoms were restlessness, increased respiratory rate, renal and intestinal disorders, decrease in blood sugar, decrease in blood coagulation time, decrease in red blood cell count, increase in the rate of heart beat, and paralysis of the hindquarters. Subcutaneous injections resulted in complete necrosis of the abdominal wall, including the skin. The mice that survived developed tumors on the shoulders; two mice experienced evisceration, and the eye of one completely atrophied.

The minimal lethal dosage of the fresh alga was found to be 0.0933 mg./g. of body weight in mice. The toxic factor was soluble in ethanol or water and was rendered inactive when autoclaved at 15 psi pressure for 20 minutes; it affects the neuromuscular and respiratory systems of albino mice.

Gorham (1964) reviewed the literature on toxic algae as a public health hazard. He concluded that the fish and livestock poisons produced by waterblooms were nuisances and economic hazards rather than public health hazards. It was estimated that the oral minimum lethal dose of decomposing toxic *Microcystis* bloom for a 150-pound man would be 1 to 2 quarts of thick, paint-like suspension. Gorham stated that this amount would not be ingested voluntarily; however, in the case of an accident, such a quantity might be ingested involuntarily.

Mackenthun and Ingram (1967) chronologically listed 20 outbreaks of human gastrointestinal disorders, 14 recorded human respiratory disorders, and 10 human skin disorders, all associated with algae.

Aquatic Vascular Plants

In the long-term cycle of the change in the aquatic terrain there is a continuing tendency for the land to encroach upon shallow ponds and shallow areas of lakes, decrease their size, make them more shallow, and eventually return them to dry land. Rooted aquatic vegetation plays a prominent role in this gradual process by invading shallow water areas through entrapment of particulate silt that is carried into lakes and ponds. The rooted vegetation will continue to spread as water areas become more shallow and the bottom mud provides suitable anchorage for roots. Plants contribute also to the filling in of lakes through both the precipitation of calcium carbonate and the accumulation of their remains upon death and decay.

While these lake invasion and encroachment activities by higher aquatic plants may sometimes be sufficiently rapid to be recognized by those who habitually use the lake, the common objections to rooted vegetation stem from their immediate interference with recreational use such as outboard motor propeller clogging, and encroachment on navigation channels and swimming beaches. The depth of water determines the adjustment of aquatic seed plants into three principal categories. Emersed weeds are those that occupy shallow water, are rooted in bottom mud, and support foliage, seeds and mature fruit one or more feet above the water surface. Cattails and rushes are familiar examples. Surface or floating weeds generally grow in deeper water at the front of (and oftentimes commingling with) the emersed weeds. The larger floating weeds are water lilies that may be rooted in the mud of the bottom and bear large leaves that float upon the surface. Smaller types such as the duckweeds are free-floating. Submersed aquatic growths often form a belt or zone of herbage farthest from shore. Except for those forms that dwell in quiet waters, they are rooted to the bottom. Depth varies considerably within this zone and may extend down to the limits of effective light penetration.

Physical factors, such as light intensity, water temperature, wave action, flow velocity, water depth and type of substrate, all interact to govern establishment of weed beds or weed sparsity, and determine the rate at which they grow. Many submersed plants continue active in winter, provided ice and snow cover are not sufficiently opaque to reduce light pentration so that growth is impeded. Once established in an area, rooted aquatic plants exhibit a high degree of persistence and efficiency of propagation. Some reproduce only by means of seeds formed in insect-pollinated flowers borne at or above the water surface; others may propagate by buds, tubers, roots, and node fragments in addition to producing viable seeds. Factors that limit growth include lack of sufficient light, insufficient nutrients, physical instability because of water level fluctuation and current and wave action, an unsuitable bottom stratum, and competition by other plants and animals.

Aquatic vascular plants are most abundant in old lakes or those fertile water bodies in which there has been thick deposition of soil from land erosion. These plants provide food, shelter and attachment surfaces for other organisms, dissolved oxygen to the water under favorable light conditions, remove and temporarily store nutrients, and serve as spawning or as schooling areas for some fish. Plant populations may become sufficiently dense to limit or restrict water use by physical obstruction, to remove large quantities of water through transpiration, and to contribute to the stunting of fish populations. Upon death and decay, stored nutrients are released for the development of new generations of aquatic biota.

Dispersal of water plants is accomplished largely by water transport, migratory birds, and, to a lesser extent, domestic and other animals. Seeds may remain viable after passing through the digestive tract of animals, and seeds and other means of propagation may be transported by animals externally. Water plants usually produce an abundance of seeds, but propagation through vegetative means is a most effective method of distribution. A small broken portion of a healthy plant may soon reestablish itself, when, in settling out of water, it roots again on a suitable substrate. Most aquatic plants are perennials and are well adapted to withstand heavy cropping by animals.

Ducks commonly feed on the seeds, tubers, rootstocks, and foilage of water plants. Martin and Uhler (1939) in a summary based on a study of the stomach contents of 7,998 ducks of 18 species collected in 247 localities scattered in all but 6 of the States and in one Canadian province reported that nearly half the food consumed was derived from the higher freshwater plants (table 14).

For many years, aquatic and bank weeds in irrigation and drainage systems in the Western States have caused serious financial losses annually (Timmons, 1960). Submersed water-weeds such as pondweeds (*Potamogeton* spp.) reduce the flow in channels, causing higher water levels, breakage in canal banks, increased seepage into adjoining croplands, greater losses of water by evaporation and inadequate delivery of irrigation water to farms or inadequate drainage of water from croplands. Decreased flow velocity causes increased sedimentation; this reduces capacity and makes more frequent mechanical cleaning necessary. Algae and weed fragments clog sprinklers, pumps, screens, valves, and pipes, and create problems at pumping plants in irrigation and drainage systems. Emergent aquatic weeds such as cattails (*Typha* spp.) and bank weeds, and phreatophytes like willows (*Salix* spp.) and salt cedar (*Tamarix pentandra*) transpire tremendous quantities of water from canals and reservoirs into the dry air. Weeds prevent proper inspection and maintenance of irrigation and drain canals.

Table 14. Plants that constitute over 1 percent of the total game duck food. (From Martin and Uhler, 1939.)

Pondweed *Potamogeton*	11.04	Wild rice *Zizania*	1.95
Bulrush *Scirpus*	6.42	Chufa *Cyperus*	1.41
Smartweed *Polygonum*	4.71	Watershield *Brasenia*	1.36
Wigeongrass *Ruppia*	4.27	Spikerush *Eleocharis*	1.25
Muskgrass *Chara*	2.47	Duckweed *Lemnaceae*	1.23
Wild millet *Echinochola*	2.38	Waterlily *Nymphaea*	1.07
Wild celery *Vallisneria*	2.33	Coontail *Ceratophyllum*	1.04
Naiad *Najas*	1.98		

A survey conducted in 1948 by the Bureau of Reclamation of the U.S. Department of the Interior (Balcom, 1950) showed that nearly 150,000 acre-feet of water were lost each year by evapotranspiration in the Bureau's 14,075 miles of canals and laterals because of weeds. By assigning a productive value of $20 per acre-foot to this lost water and adding the cost for ditch-bank repairs and damage to flooded crops attributed to weeds, the loss in irrigation systems built by the Bureau of Reclamation was estimated at nearly $3 million annually. When these loses were projected to all irrigation systems in the 17 Western States, by using the 1940 Census figures of 120,386 miles of unlined canals, an estimate of $25.5 million loss annually because of weeds was obtained.

In 1957 these figures were updated (Timmons, 1960). The total annual water loss from transpiration, increased evaporation, and overflows because of aquatic weeds in the 17 Western States was estimated at 1,966,068 acre-feet; this would have been sufficient to irrigate 330,000 to 780,000 acres of cropland depending upon the length of the growing season, evaporation losses, and other factors. The total cost of losses caused by weeds for the 17 Western States was estimated at $5,739,164. The total cost of weed control in these States was $8,113,297.

Animals

Sponges in irrigation systems can cause hydraulic problems when growing in association with other aquatic animals and plants. This undesirable effect is compounded by the favorable substrate they create for a wide variety of other aquatic pest organisms.

"The fresh water Bryozoa, or "pipe moss," are a group of invertebrate aquatic animals that are often mistaken for a mat of dead moss. Colonies of these animals are plant like in appearance except for their coloration, which is brownish-white. Bryozoa attach to logs, rocks, and other submerged objects, usually where the light is relatively dim. They have been found on a number of irrigation systems growing in profusion on concrete canal linings, submerged inlet screens, louvers, trashracks, and on the inside of pipes. The individual animal is microscopic, more or less cylindrical with a thin-body wall. These animals secrete a thin protective layer about the body wall. Many of the individual animals grow in close association with one another to produce a connected, highly branched, antler-like colony. The protective coatings of these colonies of animals are the most conspicuous feature, being massive and tough, or delicate and gelatinous, depending on the species. Oftentimes, young colonies continue to grow on the remaining protective layers of the dead animals, and produce a thick mat on a solid substrate." (Otto and Bartley, 1965.)

Bryozoa growing on submerged water sturctures and in conduits have been known to create serious hydraulic problems for water distribution structures. Two bryozoan species known to infest Bureau of Reclamation irrigation systems sufficiently to become problems are *Plumatella repens* Linnaeus and *Fredericella sultana* Blumenback (Otto and Bartley, 1965.)

Midges or blind mosquitoes, have created nuisance problems around the shores of a number of lakes. The creation in New York City during 1936 and 1937 of Fountain and Willow Lakes, high in organic content, on what had previously been salt marsh meadow open to tidal action, apparently created optimal conditions for the breeding of a number of species of chironomids. As a result, midge adults were present in enormous numbers near the shores of these lakes within the World's Fair site during the summer of 1938 (Fellton, 1940). The waters apparently were very rich because the organic matter originally present on the bottom began decomposing as soon as flooding occurred. Raw sewage was added to the lakes, and much of the fertilizer applied on grass and ornamental plants near their shores was soon washed into the water. Laboratory experiments to guide control operations were performed with a number of chemicals; these resulted in the use of rotenone as a control agent at concentrations of 6 and 10 p.p.m. Concurrently, copper sulfate was applied to control the algae.

For a number of years Winter Haven, Fla., has expected blind mosquito problems from two adjacent lakes that receive raw sewage and treated effluent from the city. The midge involved was identified as *Glyptotendipes paripes* (Edwards); Provost (1958) attributed its overproduction to excessively fertilized waters. Because midges feed almost exclusively on algae, lakes rich in algal production are likely also to be high in midge production. Since emergence of the adults takes place from the entire surface of a lake at approximately the same time, nuisances result from the mass of numbers.

The periodic appearance of a large number of gnats, *Chaoborus astictopus* Dyar and Shannon, during the summer has presented a problem to residents of Clear Lake, Lake County, Calif., for many years and has adversely affected a large resort business (Hunt and Bischoff, 1960). Clear Lake has an area of over 41,600 acres. Walker * found that emergence took place from late April to early October with peak emergence in late July or early August. A series of tests over 2 years showed the average total seasonal emergence to exceed 500 gnats per square foot. Walker calculated that the total seasonal production on the upper arm of the lake, comprising 44 square miles, approximated 712 billion gnats or 356 tons of organisms. One night's emergence was estimated at 3½ billion, and bottom samples contained as many as 1,000 per square foot.

Serious outbreaks of the midge, *Chironomus plumosus* (Linnaeus), have plagued residents and industries in the Lake Winnebago area of Wisconsin for years. Winnebago is a large, shallow, fertile lake of 137,000 acres.

Adult mayflies have caused damage in certain local areas (Burks, 1953). Unusual hordes of these insects may leave the water on the first suitable day for hatching after a period of adverse weather. The adults are fragile insects that die within a few hours; when occurring in hordes their dead bodies may clog ventilator ducts and sewers and may cause temporary traffic difficulties. On July 23, 1940, at Sterling, Ill., mayflies piled as high as 4 feet blocked traffic over the Fulton-Clinton highway bridge for nearly 2 hours. Fifteen men in hip boots used shovels and a snowplow to clear a path.

Fremling (1960) reported on mayfly problems caused by the large burrowing mayfly [*Hexagenia bilineata* (Say)] in some areas of the Mississippi River. Upon emerging ". . . the mayflies rest on terrestrial objects during the day, and under their weight tree limbs become pendulous and even break. Residents of summer homes along the river find their houses covered and their yards littered by the insects. A constant rustle is heard as the insects are disturbed and fly up from their resting places. The dead insects and their cast nymphal exuviae form foul-smelling drifts where they are washed up along the shore. . . . Crews of the towboats which transport freight on the Upper Mississippi River find mayflies to be a navigation hazard. . . . Visibility is greatly reduced by the mass of insects in the searchlight beams. The crushed insects render the decks, ladders and equipment of the boats slippery and dangerous. The towboats must of necessity be completely hosed off with water after each encounter with a large swarm of mayflies."

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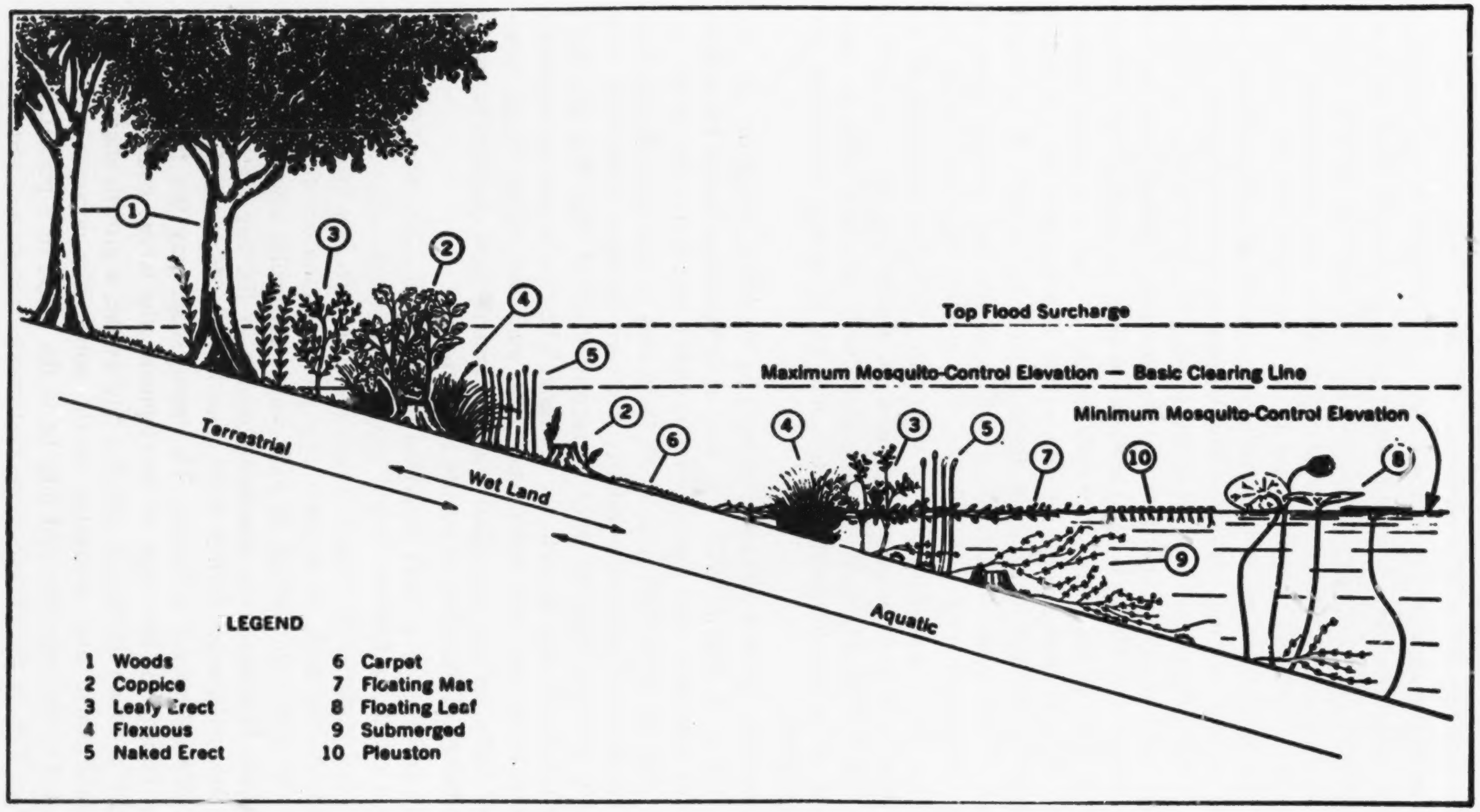
* Walker, J. R., 1949. The Clear Lake Gnat, *Chaoborus astictopus*—A Review of Investigations and the Proposed 1949 Clear Lake Treatment Program. Bureau of Vector Control, Department of Public Health, California, 12 pp. (mimeo).

Caddisflies have created serious nuisance and health problems at Keokuk, Iowa (Fremling, 1960). They swarm around the city lights during most of the summer and often blanket store windows. Masses of the insects dart into the faces of passersby, flutter under their eye glasses and fly down open-necked clothing. The minute setae that are dislodged from the wings and bodies of the caddisflies cause swelling and soreness in the eyes of hypersensitive individuals. Many Keokuk residents have become hypersensitive to caddisfly emanations and have developed typical hay fever symptoms. Fremling goes on to say that it is inadvisable to paint houses along the river bluff during the caddisfly season, and outdooor lighting is impractical. Spider webs become pendulous with captured caddisflies, making the riverside homes unsightly. Allergic reactions to caddisflies in the Fort Erie area have been reported by Parlato (1929, 1930, 1932, 1934), and by Osgood (1934, 1957a, 1957b).

Mosquitoes are implicated in the transmission of parasitic and other diseases. Elephantiasis, characterized by massive glandular swelling, is a disease that occurs commonly among the people of Puerto Rico (Faust, 1939). The disease is caused by filarial worms, *Wuchereria bancrofti* which are slender nematode parasites that invade the circulatory and lymphatic systems, muscles, connective tissues or serous cavities of vertebrates. *Wuchereria bancrofti* are carried by 41 species of mosquitoes.

The three principal arthropod-borne viruses in the United States are western equine, eastern equine and St. Louis encephalitis (Hess and Holden, 1958). Western equine and St. Louis encephalitis occur primarily in the 22 Western States, whereas eastern equine encephalitis occurs primarily in the Atlantic and Gulf coast States. Birds serve as natural hosts, and mosquitoes as vectors, for all three viruses. Man is an accidental host, but clinical disease in man is produced by all three viruses.

Mosquitoes, as a nuisance, inflict financial loss in various ways. In some sections they restrict the vacation season by inflicting painful bites, with subsequent loss of patronage to resort establisments. They attack domestic animals and fowl and, when bites are inflicted in large numbers, cause loss of weight and health. It has been estimated that 500 mosquitoes will draw $\frac{1}{20}$ of a pint of blood per day from an exposed animal (Ross, 1947). Sometimes mosquitoes become so abundant as to interfere with or stop work by man, with a consequent loss of labor and accom-


Top Flood Surcharge
Maximum Mosquito-Control Elevation — Basic Clearing Line
Minimum Mosquito-Control Elevation
Terrestrial
Wet Land
Aquatic
①
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⑥
⑦
⑧
⑨
⑩
LEGEND
1 Woods
2 Coppice
3 Leafy Erect
4 Flexuous
5 Naked Erect
6 Carpet
7 Floating Mat
8 Floating Leaf
9 Submerged
10 Pleuston

Figure 77. Generalized contour distribution of basic plant types on the shoreline of a main-river reservoir (from Bishop and Hollis, 1947).

plishments. Mosquitoes are among the worst nuisances of the out-of-doors and prevent enjoyment of recreational facilities by many people seeking exercise and relaxation.

Most mosquitoes breed in still water; small ponds and pools of many types, the shallow edges of lakes, and the still water in shallow, dense, weed beds along the edges of streams and lakes, and accumulated algal masses serve as ideal habitats. They prefer areas with little wave action, an abundant cover of aquatic vegetation, an abundant food in the form of humus or other organic matter on the bottom, and surface floating particles of microorganisms. The mosquito production of a lake or reservoir appears to be directly proportional to the amount of intersection line between plants (or flotage) and the water surface. Likewise, the relative mosquito production potential of different plant types is in direct proportion to their relative amount of intersection line per unit area of water surface, other factors being equal. Bishop and Hollis (1947) found a difference in the relative intersection values among the various types of aquatic vegetation (figs. 77 and 78). For a given plant species the intersection value, and therefore the mosquito production potential, varies according to the percentage of vegetation cover occurring at the water surface. The highest intersection values are usually produced with an intermediate cover; low intersection values may be associated with either low or high covers.

The attacks on man and other animals by blackflies, *Simulium* spp., are described by Belding (1942). The bite, at first painless except for a slight prickling sensation, later produces an ulcer-like sore that is due to the salivary toxin. In susceptible individuals there may be marked inflammation, local swelling, and general incapacity. Exposed portions of the body such as head, neck and legs are most frequently attacked. The flies also have the havit of crawling beneath the clothing. They are a pest to fishermen and woodsmen and may incapacitate both man and animal. Large numbers of cattle, horses and other domestic animals have perished from the depredations of these flies in Europe and America.

Otto and Bartley (1965) described problems caused by blackflies in irrigation canals as follows: Pupal encasements create extensive areas of roughened surfaces that increase resistance to waterflow in canals. In its life history, the adult fly deposits eggs on vegetation or other solid substrate just under the surface of swift water, especially where the current is broken. Overwintering sometimes occurs in the egg state. The eggs hatch below the water surface to produce larvae, which attach themselves to a solid submerged substrate. The larval stage may last from 2 to 6 weeks. During the last stage of development, the larvae construct silken cocoons in which the insects develop into pupae, a growth stage preceding development and emergence of the adult. The cocoons are firmly cemented to the substrate and may be in the shape of a pocket, slipper, or vase. This is the growth stage that creates roughened surfaces on a

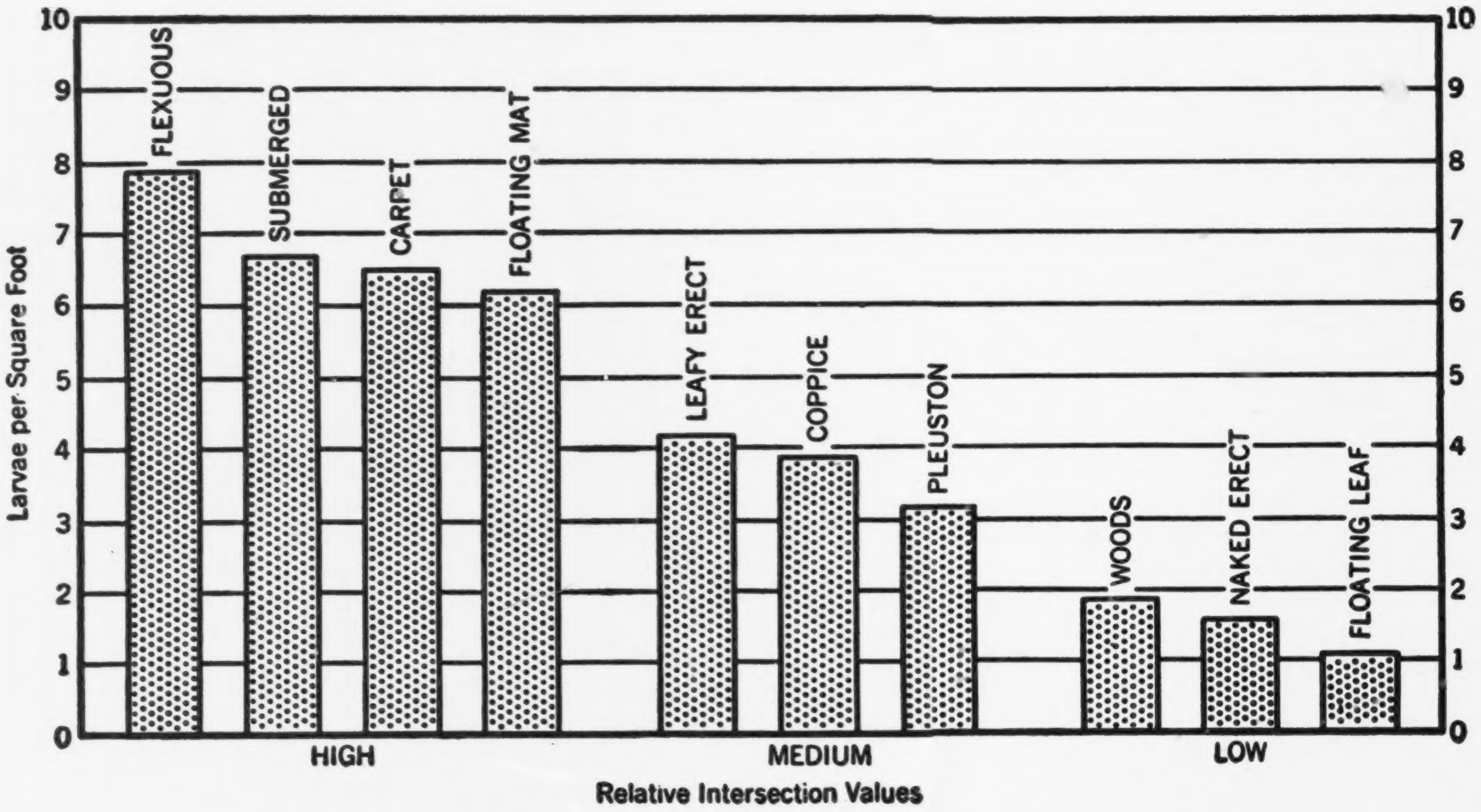

Figure 78. *Anopheles quadrimaculatus* Say production potentials of basic plant types (from Bishop and Hollis, 1947).

canal lining. The pupae are oval and enlarged at the upper end, and are yellow to red-brown in color. They have small abdominal hooks by which they remain attached to the cocoon. The pupal stage usually lasts from 2 to 8 days prior to emergence of the flying adult. The pupal cases generally are quite persistent following emergence of the adult insects, and often require mechanical removal from canal linings.

Deer flies and horse flies, *Chrysops* spp. are of medical importance not only as aggressive bloodsucking pests, but also because certain species transmit diseases to man and animals. As mechanical vectors they may carry pathogenic organisms on their mouth parts and bodies. *Chrysops discalis* Williston, the western deer fly, can transfer tularemia, *Pasteurella tularensis* to both man and animals and remains infective for at least 2 weeks (Belding, 1942). Occasionally anthrax germs also are carried on the beaks of horse flies and deer flies between diseased and healthy animals and sometimes to man. Deer flies often attack man.

Leeches abound in warm, protected shallow water where there is little wave action and where plants, stones, and debris offer concealment. They are chiefly nocturnal in their activities and reamin hidden under stones and vegetation in daylight. The majority of specimens are found from the water's edge to a depth of approximately 6 feet. Leeches require substrates to which they can adhere and consequently are rare on pure mud or clay bottoms. Some species persist in intermittent ponds by burrowing into the mud bottom where they construct a small mucous-lined cell in which they live. Leeches are dormant in winter, burying themselves in the upper part of the bottom material just below the frostline.

Any disturbance of the water, such as is caused by a wading animal, attracts the leeches partly because of the mechanical disturbance that stimulates the tactile organs and partly because of the animal emanations that stimulate the organs of chemical sense. Thus, leeches are attracted by bathers and tend to congregate and remain about the docks and stones of the bathing area. They are strong and rapid swimmers and can invade a particular area from other sections of the lake. They are most active at maximum water temperatures, and the period of greatest prevalence in the bathing area corresponds with that of maximum water temperature in August.

Ingram (1959) discussed nuisances caused by the Asiatic clam, *Corbicula fluminea* (Müller) in California. "In 1953 C. S. Hale, general manager of he Coachella Valley County Water District, Coachella, Calif., stated in correspondence that an aparently serious infestation of *Corbicula fluminea* had developed in the water district's underground distribution system. Irrigation water is taken from the Colorado River at Imperial Dam, transported through 123 miles of open canal, and distributed through approximaely 500 miles of underground pipe. Accumulation of live clams and clamshells causes serious impairment of water delivery at farmers' turnout valves, at ends of laterals, and in irrigation sprinkler sys-

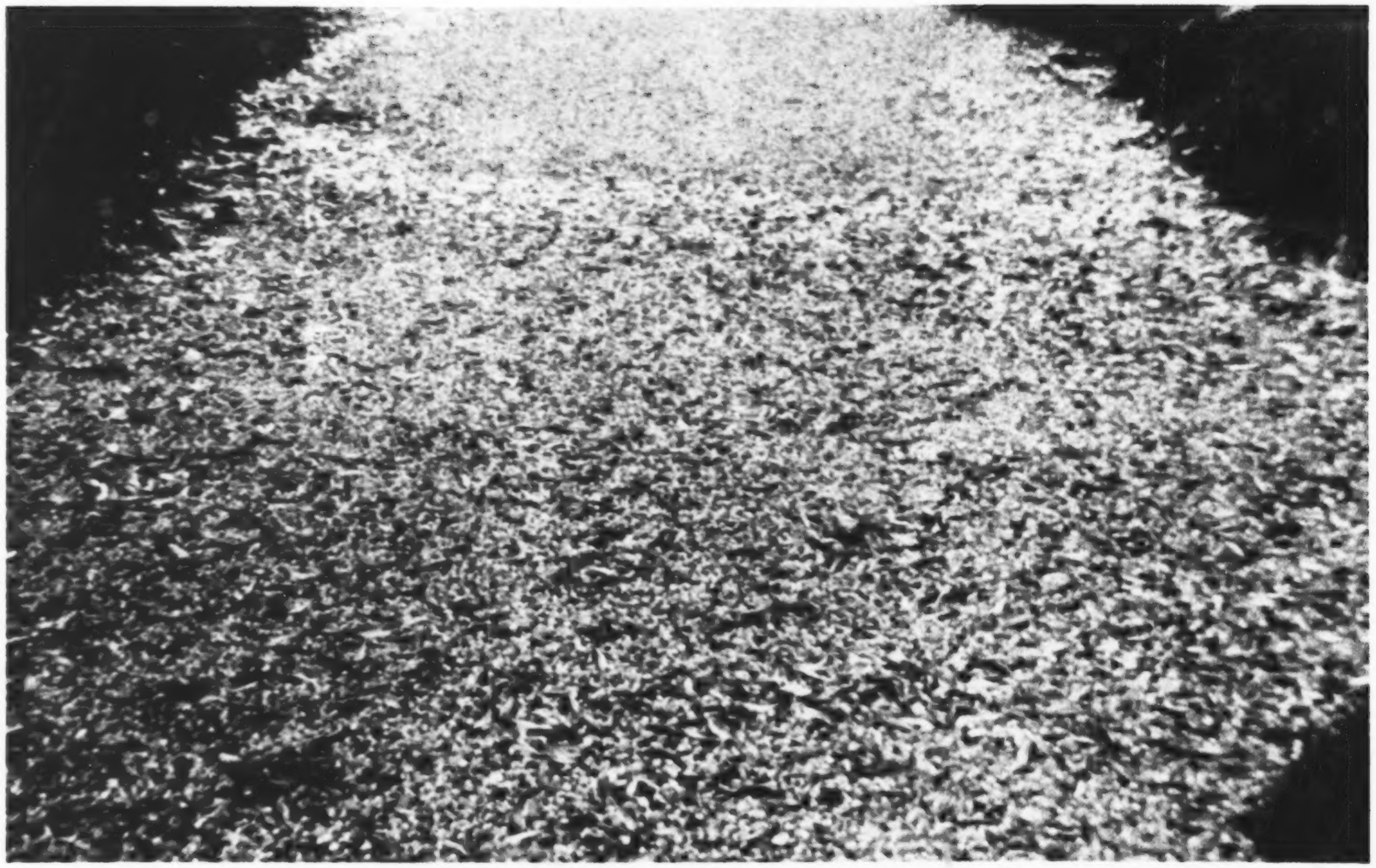

Figure 79. Interim Canal, California, with Asiatis clams completely covering canal bed.

tems. Clams were appearing in irrigation water in Riverside County and Imperial Valley distribution systems."

The Asiatic clam has caused significant problems of operation and maintenance in the South Bay Aqueduct, Calif., by reducing the cross sectional area of the Interim Canal.* The clams contributed to silt buildup in two ways: by continually moving the top of the bottom sediments and covering any material that settled out, thus holding the settled material on the bottom of the canal, and by removing suspended solids from the water through filtration and depositing the solids on the canal bed combined with a proteinaceous slime that does not readily go back into suspension. At one station in the canal the density of the clam population ranged between 380 and 1,500 per square foot. The highest density found in the South Bay Aqueduct was 5,635 live clams per square foot (figs. 79 and 80).

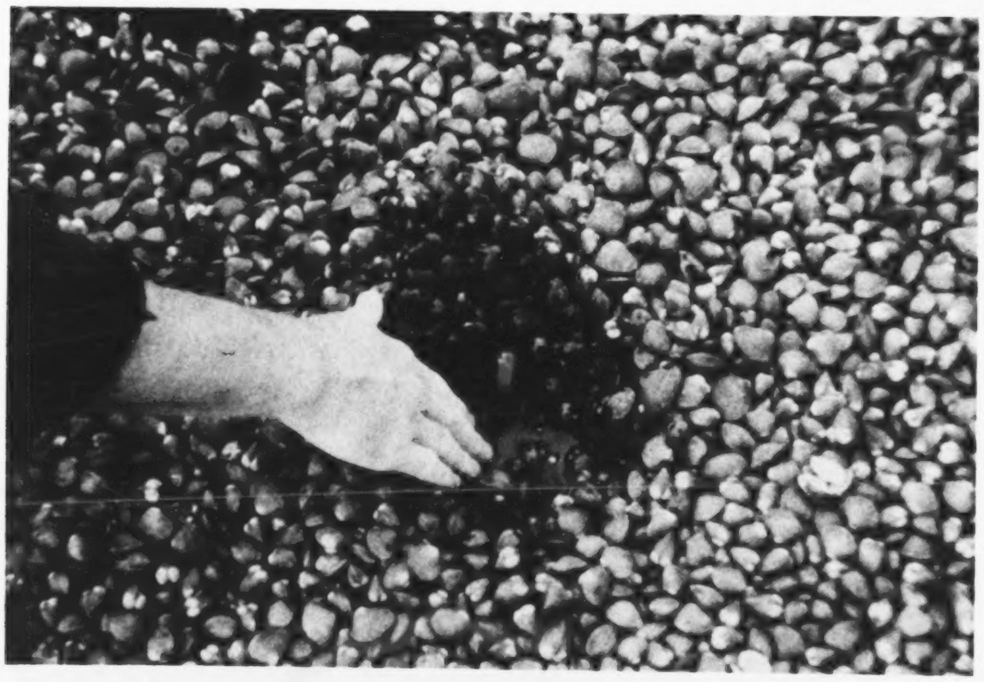

Figure 80. Closeup of undisturbed canal bed, Interim Canal, California, with multitudes of Asiatic clams.

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* Morgester, J. J. 1967. Water Quality and Biologic Conditions South Bay Aqueduct, 1962–1966. State of California, The Resources Agency, Department of Water Resources.

16

NUISANCE ORGANISM CONTROL

ULTIMATE control of nuisance aquatic organisms can be accomplished only by drastic alteration of the basic cause(s) of the problem. Generally, the introduction of organic materials and inorganic nutrients into the Nation's waterways are chiefly responsible for the explosion of an aquatic plant or animal population into the nuisance category. Drainage from fertilized lands, inadequately treated domestic or industrial waste discharges, street and storm drainages, and municipal and private refuse dumps each contributes its abundant share to the depredation of the receiving water; each must be adequately treated or controlled if this Nation's waters are to be used to the extent to which they have been projected.

The maintenance concept must be considered by all users of streams, lakes, or reservoirs. The waterfront is an aquatic extension of the surrounding land. To achieve the most lasting beauty, it must be maintained periodically in a fashion similar to that of the adjoining lawn or the abutting parkway; otherwise nuisances and unsightliness will prevail. Controls developed to cure water ills are not singular operations. The mechanism triggering nuisance development is usually such that it will reestablish itself another year. Thus, continuous surveillance as well as maintenance are necessary in water management.

Methods have been developed and perfected that effect an adequate temporary reduction and control of plant nuisances under a number of circumstances. Controls may be either mechanical or chemical, and their selection and use depend upon the nature and scope of the problem, the type and extent of the control desired and comparative costs. Mechanical controls are limited principally to rooted aquatic vegetation, whereas chemical controls have been developed for algae, rooted aquatic vegetation, and other nuisance organisms. Every control has its limitations, based upon the dimensions of the area to be treated; these limitations are broad and do not exclude overall use of the water. Controls that are recommended most generally have not been shown to seriously disrupt general lake ecology.

Chemical Usage

As reported in Weeds Trees and Turf,* the use of chemicals to control excessive growths of algae and aquatic weeds in lakes has become more widespread in Wisconsin in recent years. Dr. M. Starr Nichols, researcher with the University of Wisconsin's departments of agricultural and civil engineering is quoted as stating that from 1950 to 1958, 81 Wisconsin lakes received treatments of about 78,000 pounds of sodium arsenite per year, while 41 lakes were treated with 671,964 pounds of copper sulfate. During the past several years, the number of lakes chemically treated has continued to grow. In 1966, 150 lakes received the following treatments: 48 with copper sulfate for algal control; 16 with copper sulfate and copper carbonate for swimmer's itch control; 38 with sodium arsenite for submersed weed control; 37 with organic chemicals such as diquat and 2,4-D for weed control. Sixteen of those lakes needed more than one treatment; one lake required 13 treatments.

The British Columbia Research Council (1967) did an extensive investigation on the market for algicides. The present maximum market, predicated on probable needs rather than actual usage, and the probable growth rates were estimated as follows:

irrigation waters—600 tons per year, increasing by 2.5 percent per year
farm ponds—5,000 tons per year, increasing by 3 percent per year
recreational waters—5,000 tons per year, increasing by 5 percent per year
Red Tide—several hundreds of tons, unpredictable
swimming pools—up to 300 tons per year, increasing by 10 percent per year
municipal water supplies—15,000 tons per year, increasing by 3 percent per year
industrial waters—probably small.

The study further concluded that copper compounds, principally copper sulfate, would remain dominant in the large-scale treaments of irrigational and recreational waters, but would likely lose out to the more expensive chemical toxicants in the intermediate-scale market, unless a longer lasting copper algicide can be found that would allow a once-a-season treatment. Copper compounds were not considered to be serious competitors in the small-scale markets of swimming pools and industrial cooling ponds where fast acting bactericides are necessary and the cost per pound of the applied chemical is of less importance.

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* Vol. 8, No. 3, p. 3 (March 1969)

Harvesting

From the standpoint of nutrient removal, harvesting the aquatic crops annually would be advantageous. The economics of present methods of harvesting and the scope of the problem, however, necessitate a critical appraisal of benefits versus costs. The expected standing crop of algae approaches 2 tons per acre (wet weight) and would be expected to contain 15 pounds of nitrogen and 1.5 pounds of phosphorus. Submerged aquatic plants would be expected to approach at least 7 tons per acre (wet weight) and contain 32 pounds of nitrogen and 3.2 pounds of phosphorus. Values may be higher under severe nuisance conditions.

Some methods and equipment used for the physical and mechanical removal of water weeds are reservoir drawdown and drying, burning, hand-pulling, hand-cutting, hand-raking, chain-dragging, hand-operated underwater weed saws, and power-driven underwater weed cutting and weed removal units. The type of control employed depends on the field situation, the extent of control desired, and the labor and cost involved. The mechanical harvesting of aquatic weeds involves equipment capable of handling large tonnage of materials (fig. 81). Mechanical controls are especially valuable to reclaim shallow nuisance areas.

Algae

Chemical control measures to be employed depend upon the type of nuisance and local conditions. A good algicide or herbicide must: (1) Be reasonably safe to use; (2) kill the specific nuisance plant or plants; (3) be nontoxic to fish, fishfood organisms and terrestrial animals at the plant-killing concentration; (4) not prove seriously harmful to the ecology of the general aquatic area; (5) be safe for water contact by humans or animals, or provide suitable safeguards during the unsafe period; and (6) be of reasonable cost. Some of these factors assume added significance when based on the physical dimensions of a particular control operation. What might be suitable from both a cost and toxicity standpoint in a control program for a pond might not be feasible in a control program for specific areas on a large body of water.

For the chemical control of algae it may be necessary to know only the acreage of water requiring treatment and the methyl orange alkalinity of the water. For the chemical treatment of many aquatic pests, it is necessary to know the volume of water receiving treatment. A formula is used to ascertain the amount of chemical to apply to a given area:

$$\frac{\text{Length (ft.)} \times \text{Width (ft.)} \times \text{Average Depth (ft.)} \times 62.4 \text{ (wgt. of a cu. ft. of water)}}{1{,}000{,}000} =$$

pounds of chemical (active ingredient) needed to give a concentration of 1 mg./l. This, multiplied by the required chemical concentration in milli-

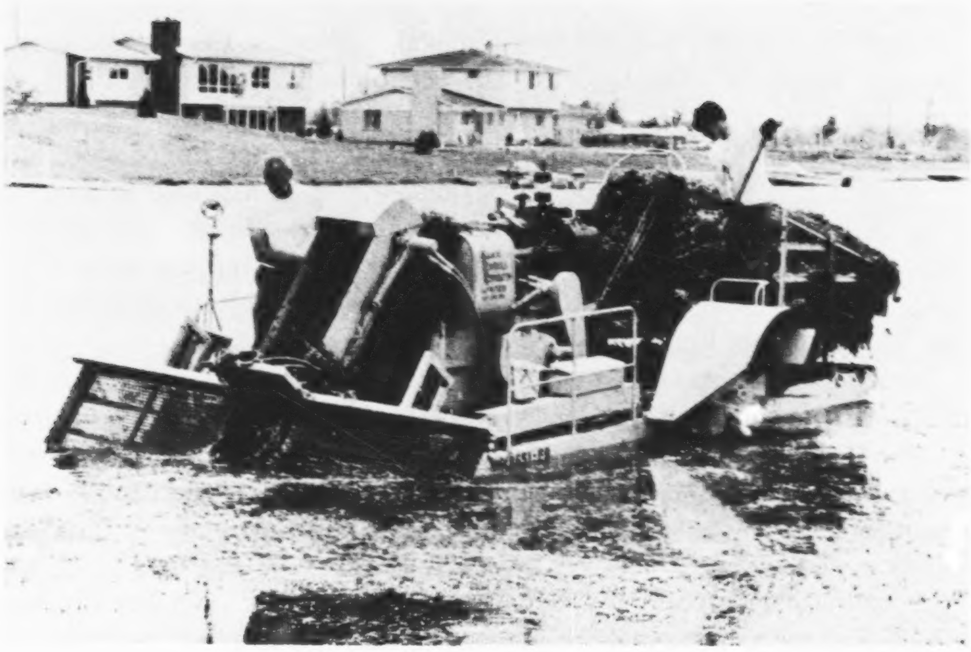

Figure 81. Mechanical weed cutting and removal.

grams per liter for treatment equals the pounds of chemical needed for the measured area. Various formulations may be purchased. For example, a formulation containing 2 pounds of active ingredient per gallon would necessitate dividing the pounds of chemical by 2 to arrive at the gallons of commercial formulation required to control the nuisance. A dosage chart is often convenient (fig. 82).

From 1904 (Moore and Kellerman, 1904) to the present, the chemical that has most nearly met specifications for the control of algae has been copper sulfate (blue vitriol). Despite its extensive usage, copper sulphate has shortcomings in that it may, in excessive concentrations poison fish and other aquatic life, it may accumulate in bottom muds as an insoluble compound following extensive usage, and it is corrosive to paint and equipment.

Definite dosages of copper sulfate for the control of various types of algae were first prescribed by Moore and Kellerman (1905); these have been reprinted extensively in tabular form with specific dosages for some 70 organisms (Hale, 1954). The practical application of such a table is limited, however, because of the many variables encountered in nature. Because the solubility of copper in water is influenced by pH and alkalinity, as well as temperature, the dosage required for control depends upon the chemistry of the water itself, as well as on the susceptibility of particular organisms to the copper. Thus, rather arbitrary dosage rates have been succesfully used, especially in the midwestern States (Bartsch, 1954; Mackenthun, 1958). Since a total alkalinity of 40.0 mg./l seems to

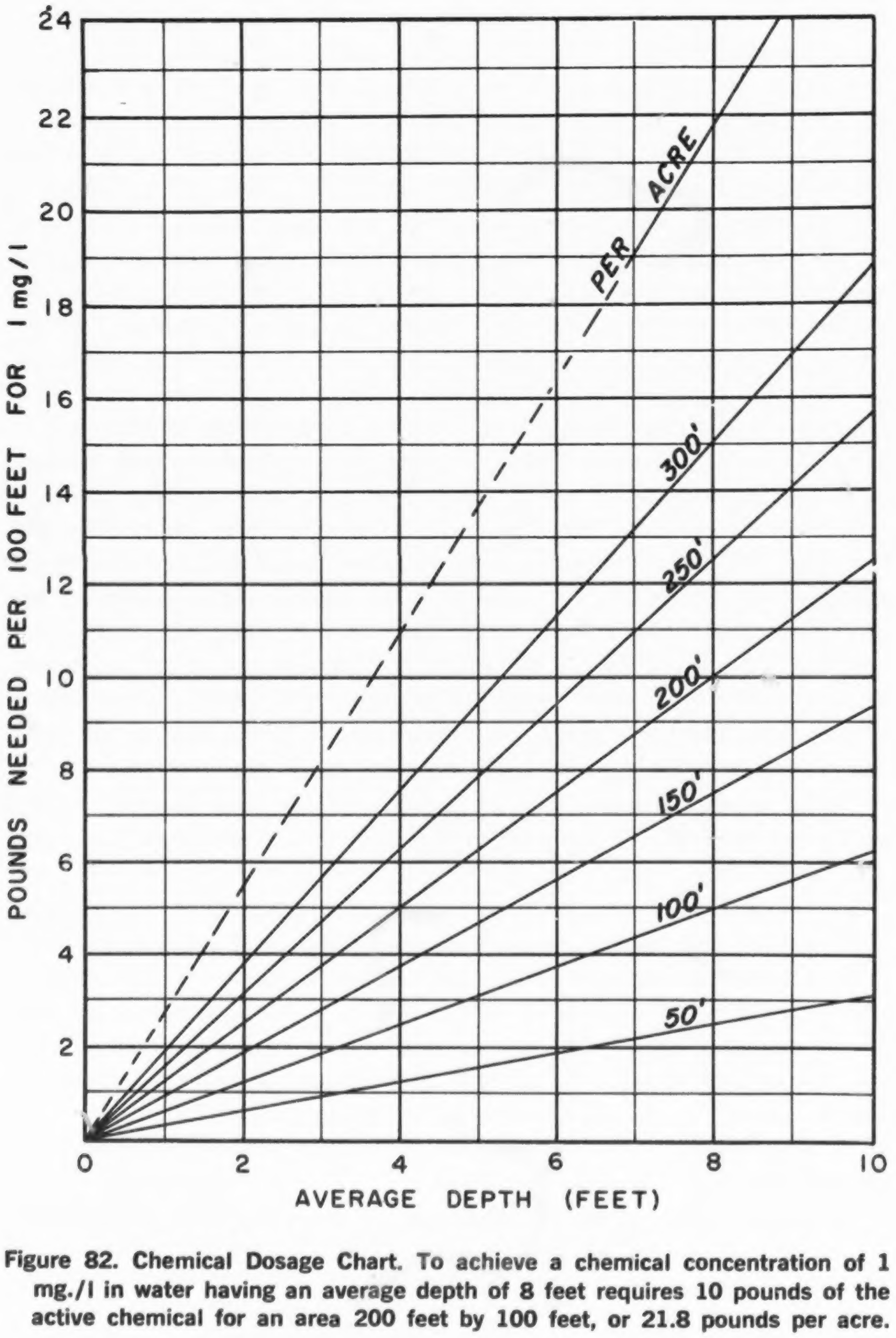

Figure 82. Chemical Dosage Chart. To achieve a chemical concentration of 1 mg./l in water having an average depth of 8 feet requires 10 pounds of the active chemical for an area 200 feet by 100 feet, or 21.8 pounds per acre.

be a natural separation point between soft and hard waters (Moyle, 1949), those lakes that have a total methyl orange alkalinity of 40 mg./l or greater are treated with blue vitriol (commercial copper sulfate) at a rate of 1 mg./l ($CuSO_4 \cdot 5H_2O$) for the upper 2 feet of water regardless of actual depth. On an acreage basis, the concentration would amount to 5.4

pounds of commercial copper sulfate per surface acre. The 2-foot depth has been determined to be about the maximum effective range of a surface application of copper sulfate in such water, since algae will be killed with increasing depth only if the rate of downward diffusion exceeds the rate of copper precipitation. The algae killed by such a treatment are those that are suspended near the water surface and occur commonly as blooms in calm weather. For lakes with a total methyl orange alkalinity below 40 mg./l, a concentration of 0.3 mg./l commercial copper sulfate for the total volume of water has been recommended. This is comparable to 0.9 pounds of copper sulfate per acre-foot of water. It is obvious that when a low-alkalinity lake has an average depth of about 6 feet, the dosage would be about the same as in a high-alkalinity lake having the same area. When lesser average depths are involved, a greater concentration of chemical results in the high-alkalinity lakes. This apparent paradox would be even more striking were it not for the fact that in low-alkalinity lakes the algae frequently are of the filamentous types that may lie at the bottom and, therefore, the entire volume of water must be calculated to insure that a sufficient concentration of the chemical reaches the algae to effect a kill. In high-alkalinity lakes, algae frequently are planktonic and tend to concentrate near the surface, which is the only stratum in which appreciable concentrations of soluble copper can be produced. Certainly, when copper sulfate is used as the algicide, the best and most lasting control will result when the lake water has a total alkalinity around 50 mg./l or less.

Algal control treatments can be marginal or complete, the type applied to a given body of water must be determined by the size, shape, and relative fertility of the water, and the estimated cost of the project. Complete treatment in which the calculated amount of copper sulfate is systematically applied over the entire surface area is the most satisfactory. It insures that a major portion of the total algal population is eliminated at one time, and that a longer recovery period is required before an algal bloom condition recurs. The interval between necessary treatments will be directly correlated with climatological conditions and the available nutrients utilized by the remaining algal cells that are not killed as a result of chemical application. One to three complete treatments per season may be sufficient to give reasonable control.

Marginal treatment, on the other hand, is a method designed to obtain temporary relief in a restricted area where more extensive activity is not feasible or financially possible. In this procedure a strip, 200 to 400 feet wide, lying parallel with the shore, and all protected bays are sprayed in the same manner as in complete treatment. No other part of the area is treated even though many algae may be present. As a result of treatment, the algal population and the intensity of odors along the periphery of the lake are reduced. The duration of freedom from the algal nuisance following marginal treatment is dependent upon the density of the algal population in the center of the lake and its ability to infiltrate the treated area through the action of wind, waves, and currents. Any marginal control operation should definitely be considered on a periodic repeat basis. If fertility is not excessive, large bodies of water might gain enough relief from marginal treatment to warrant this type of control; however, it probably would be a waste of money for a large, fertile lake that is long and narrow and subject to considerable wind and wave action. In the latter case, complete treatment might be the only present answer, the cost of which might be prohibitive.

Copper sulfate may be applied in a variety of ways: bag-dragging, dry feeding (Monie, 1956), liquid spray (Mackenthun, 1958), and airplane application of either dry or wet material. Because rapid and uniform distribution of the algicide is essential, the size and scope of the problem determine to some extent the method employed. In general, liquid spraying systems operated from a boat or barge have been most widely used (figs. 83 and 84). Because copper sulfate is a highly corrosive chemical, materials that are used in the construction of spraying equipment should be resistant to its corrosive nature.

Other methods of distributing copper sulfate have been devised; one of these is to blow a chemical dust rather than use a slurry or solution (Anon., 1965). The principal advantage of the blower-type machine is the ability to treat large surface areas rapidly with a light dosing of material.

The blower, operating at 3,000 to 3,500 r.p.m., has the tendency to grind the commercial-grade $CuSO_4$ snow into smaller particles. These

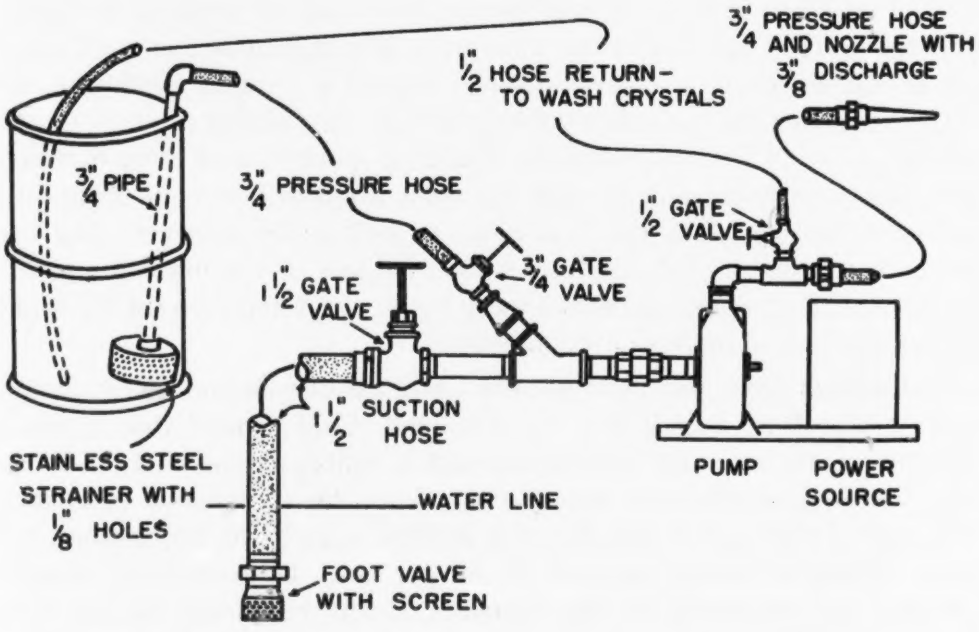
3/4" PRESSURE HOSE AND NOZZLE WITH 3/8" DISCHARGE
1/2" HOSE RETURN- TO WASH CRYSTALS
3/4" PIPE
3/4" PRESSURE HOSE
1/2" GATE VALVE
3/4" GATE VALVE
1 1/2" GATE VALVE
1 1/2" SUCTION HOSE
STAINLESS STEEL STRAINER WITH 1/8" HOLES
WATER LINE
PUMP
POWER SOURCE
FOOT VALVE WITH SCREEN

Figure 83. Equipment design for algal control. Small blue vitriol crystals are placed over perforated drum in chemical solution tank.

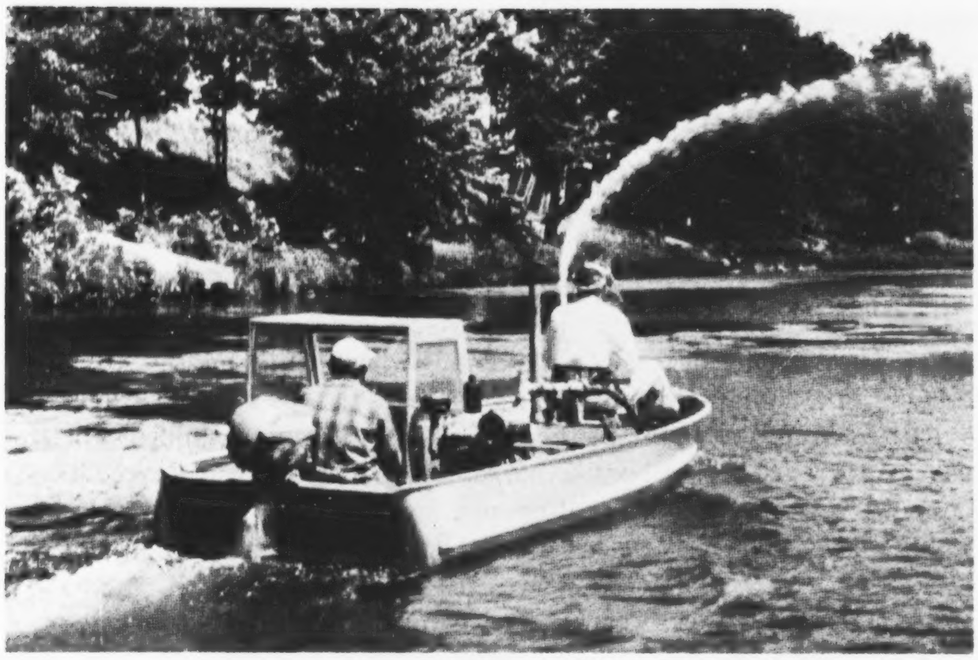

Figure 84. Liquid spray distribution of chemical by small boat.

small particles are blown into the air, and wind currents assist in spreading them over the surface of the water.

Certain disadvantages are found in the blower-type machines. For example, the larger machines are heavy enough to reduce the permissive load of chemical in the boat; and two or more men are required to transport the units in and out of the watercraft. The machines also need continual adjustment by a trainer operator, such as a contract applicator, to maintain a constant feed and to obtain an even distribution of copper. An excessive rate of feed may clog the discharge spout. Use of these blower-type machines is dependent upon the wind for distribution of chemical, and with shifting winds the boat crew, as well as the reservoir may be dusted with the material. There is always the loss of varying amounts of copper sulfate dust that is carried away by the wind and then settles upon the above-water shoreline of the reservoir.

Helicopters have also been used in chemical distribution (Rosenberg, 1964). The East Bay Water Co., Oakland, Calif., found that a more efficient treatment could be obtained with a helicopter and that, as a result, fewer treatments were required per season for a particular reservoir. The cost of chemical distribution was slightly more by helicopter than by boat. Helicopter rental averaged $0.80 per acre. DeCosta and Laverty (1964), in commenting on this treatment, stated that it was the district's experience that an ounce of copper sulfate properly applied at the reservoir was worth a pound of activated carbon added at the filter plant to correct a problem after it had arisen.

Algal control measures should be undertaken before the maximum development of the algal bloom. If, for some reason, a given area is not treated until the algal population has become dense, or a floating mat has formed, judgment must be used to determine the area that should receive treatment at any given time, lest sufficient organic matter is killed to result in oxygen removal when decomposing. It is good practice to subdivide the total area into sections and control the nuisance in one section at a time. Other sections may be treated after an interval of 7 to 10 days to ensure that sufficient dissolved oxygen is present to satisfy the demands of the decomposing algae.

Particular algal species often require particular chemical application measures and sometimes particular algicides. For example, the Ontario Water Resources Commission (Anon., 1959), in its examination of control measures for *Cladophora* in Lake Ontario, found that copper sulfate merely retarded growth but Aqualin at 5 p.p.m. cleared the test plots of *Cladophora* and they remained clear for 4 weeks during which observations were taken. In inland lakes and ponds, Diquat has been recommended for *Cladophora* control along with copper sulfate (De Vaney, 1968).

A problem often encountered in farm ponds is that of thick yellowish-green or green scums that form on the pond's surface. Scum-forming green algae are *Hydrodictyon, Pithophora, Cladophora, Oedogonium, Zygnema, Mougeotia,* and *Spirogyra*. The optimum time to control these growths is in early developmental stages when they first appear on the water surface. Using copper sulfate dosages that were discussed earlier, it may be necessary to spray-treat the area on successive occasions to achieve control. Care should be exercised to prevent killing too much algae at one time or fish may be killed by a lack of dissolved oxygen when the algae decompose. Mechanical removal of much of the scum, when feasible, will do much to enhance the success of the chemical application.

Another algal problem, discussed earlier, is *Chara*. *Chara* often is troublesome in high alkalinity (>40 mg./l) ponds and lakes, and in ponds may render them relatively unproductive of fish. Like the control of pond scums, *Chara* control chemicals should be applied early in the season before portions of the plant begin to decompose, and before the growth has "rolled" from the bottom. *Chara* is readily susceptible to copper sulfate applied at 5.4 pounds per acre, but the chemical must be applied directly above the growth. The algicide may be introduced through a perforated "⊥" pipe that is attached to the discharge side of the chemical distribution equipment and then lowered to the desired depth for chemical introduction.

The British Columbia Research Council (1967) published a compendium of algicides listing active ingredients, application rates, toxicities and restrictions, and costs for 31 formulations used in farm ponds, irrigation and drainage canals, recreational lakes, municipal water supplies, swimming pools, and industrial waters.

Vascular Plants

In the control of submersed aquatic plants, it is often desirable to chemically treat localized areas along the shoreline, such as bathing beaches and around piers, and to develop channels through weed beds so that boats will have access to deeper water. Sometimes it is advantageous to treat an extensive area in an effort to curtail an advancing population of a weed species, such as Eurasian watermilfoil (*Myriophyllum spicatum* Linnaeus). Best results are obtained when the shoreline areas are treated because currents and wave action are usually minimized, and the diffusion of the chemical can take place only in one direction—into the lake. There are limitations below which it is usually not feasible to attempt liquid chemical weed control. The recommended minimum area to be treated is 200 by 200 feet. The treatment of very small areas permits the diffusion of the chemical on 3 sides, thus reducing the concentration of the chemical within the area to a point below the toxic level for rooted plants. An exception to this recommendation might be a small slough, bay, or stagnant channel with an area of less than 40,000 square feet. Granular aquatic herbicides, applied early in the growing season, are often applied successfully on smaller areas.

For many years, arsenic trioxide as a sodium arsenite solution was used effectively to control submersed aquatic vegetation (Mackenthun, 1958). In recent years the trend has been away from those chemicals that are essentially nondegradable to organic herbicides that do not accumulate in the environment. These herbicidal formulations include the phenoxy compounds such as 2,4-D and silvex, Dalapon, Diquat, Endothall, and others. Dosage rates and application procedures have been detailed by Surber (1961), Lawrence (1962), and De Vaney (1968). De Vaney has listed those herbicides that have been registered in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act for use in aquatic sites (table 15). Many of the compounds are available in liquid and granular formulations, the latter being suitable for broadcasting on the water surface (fig. 85).

A few details should be kept in mind in the application of a chemical. It has been found advantageous, for example, to divide a large area to be treated into a convenient number of small subareas and to accurately determine the volume of water each contains. Since the quantity of the chemical used is proportional to the water volume to be treated, it is a simple matter to properly adjust the chemical application and evenly distribute the correct amount of chemical into the subarea. This procedure is then repeated in successive subareas. Spraying should be initiated at the shoreline so that fish will not be trapped in shallow water.

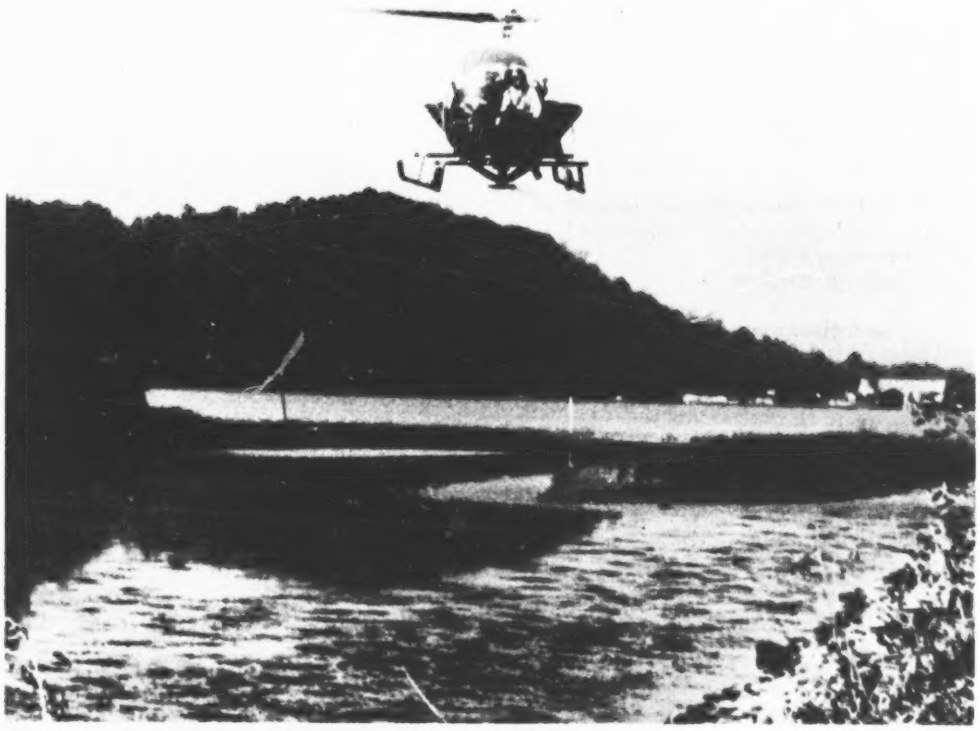

Figure 85. Helicopter application of a granular herbicide.

Chemical control of aquatic vegetation must currently be regarded as a temporary remedy although it should last for the season in which it is applied. Under certain conditions, the removal of a vascular plant population may promote the growth of a bottom-dwelling alga such as *Chara*. The alga must then be attacked with a suitable algicide.

Biological controls are currently being tested in the control of aquatic weeds. Preliminary studies on use of grass carp, *Ctenopharyngodon idellus*. (Cuvier and Vallenciennes), for aquatic weed control have recently been completed at Auburn University Agricultural Experiment Station. When stocked at a rate of 685 per acre, the fish eliminated 12 species of weeds growing in plastic-lined pools within 6 weeks. In ponds, 3 species of rooted weeds were significantly reduced or eliminated in 1 month after being stocked with 20 to 40 grass carp per acre (Avault, 1965).

Stevenson (1965) reported that early growth of the grass carp at the Fish Farming Experimental Station, Stuttgart, Ark., compared favorably with that reported in semi-tropical countries. The average weight at 18 months was 1,816 grams; the length, 50 centimeters. The fish were given a supplemental ration of commercial fish pellets and cut grass. Observations of the feeding habits indicate that this carp may not be a strict herbivore; it is recommended that a thorough study be made before the fish is released in natural waters. Stevenson calls it the most efficient aquatic

Table 15. Herbicides That Have Been Registered in Accordance With the Federal Insecticide, Fungicide, and Rodenticide Act for Use in Aquatic Sites.
(From DeVaney, 1968)

- Acrolein
  - Irrigation canals
  - Ponds
- Amitrole (Not approved for Bureau of Sport Fisheries and Wildlife use)
  - Non crop areas
  - Drainage ditches
- Amitrole T (Not approved for Bureau of Sport Fisheries and Wildlife use)
  - Non crop areas
  - Drainage ditches
  - Marshes
- Ammonium Sulfamate
  - Around lakes, ponds
  - Around potable water reservoirs
  - Along inflow streams
- Bromacil
  - Ditch lands (drainage)
- Copper Sulfate
  - Farm ponds
  - Lakes
- Dalapon
  - Non crop areas
  - Drainage ditches
- Dichlobenil
  - Lakes
  - Ponds
- Dichlone
  - Lakes
  - Ponds
  - Irrigation canals
- Diquat
  - Lakes
  - Ponds
  - Irrigation canals
  - Drainage ditches
- Endothall
  - Lakes
  - Ponds
  - Irrigation canals
  - Drainage ditches
- Fenac
  - Lakes
  - Ponds
  - Reservoirs
  - Drainage ditches and banks
- Petroleum Distillate (aromatic)
  - Irrigation ditches
  - Drainage ditches
  - Irrigation, drainage ditches and banks
- Silvex
  - Lakes
  - Ponds
- Sodium Arsenite (Not approved for Bureau of Sport Fisheries and Wildlife use)
  - Lakes
  - Ponds
- Sodium TCA
  - Non crop areas
  - Ditch banks (drainage)
- 2, 4-D
  - Lakes
  - Ponds
- 2, 4, 5-T
  - Lakes
  - Ponds

plant-eating fish, but cautions that it might become another carp problem if introduced.

Rapid advances are also being made in research on the control of marsh weeds and other aquatic forms that project above the water surface. Two factors explain the growing interest in the control of these weeds: one is the advent of new and better herbicides for the purpose; the other is the increasingly critical situation facing the Nation's waterfowl hunting resource—a sport on which 2 million Americans spend millions annually. Already more than half of the country's original 125 million acres of wetlands have been spoiled for waterfowl use. As the national population approaches the 200-million mark, more and more of the places where ducks feed, breed, and are hunted will have to be converted to the needs of advancing civilization. In other words, prospects are for fewer hunting places and fewer ducks for a large number of hunters.

To help offset this trend, it is important to make the best use of available waterfowl habitat. Thousands of poor or fair areas in the United States can be made more attractive for ducks and duck hunters by replacing marsh weeds with plants that furnish food or cover for waterfowl. Commonly, the costs involved are not prohibitive (Martin et al., 1957).

In Florida recently, water hyacinths and other pest plants were cleared from 20,000 acres of ponds and lakes by the Game and Fresh Water Fish Commission. Numerous other programs, both large and small, are being waged against phragmites, cattails, waterchestnut, and other marsh weeds in various States. In the Federal refuge system, more than 2,000 acres of marshlands are treated with herbicides annually to make them more productive for waterfowl.

Martin et al., discussed vegetation control by waterlevel management, mechanical control by bulldozing, burning, and the use of herbicides such as 2,4-D, 2,4,5-T, ammonium sulphamate, Dalapon, Kuron, and others. Specific recommendations for chemical control of particular marsh plants were given.

Animals

Problems have arisen in the chemical control of certain animal pests. Clear Lake, Calif., was treated in September 1949, with a chlorinated hydrocarbon insecticide DDD (dichlorodiphenyl dichloroethane) at a concentration of 1 part of active insecticide to 70 million parts of water to control the Clear Lake gnat. It was determined that a 99-percent kill of larvae resulted. A second chemical application was necessary in 1954 and a third in 1957. These latter applications were calculated to produce a concentration of one part in 50 million parts of water. Following both the 1954 and 1957 applications, 75 to 100 western grebs were found dead along the lake shore. Results of chemical analysis of the fatty tissue from the grebes in 1958 indicated DDD was present at the unusally high concentration of 1,600 p.p.m. (Hunt and Bischoff, 1960). The amount of DDD found during Mar. 1958, in the visceral fat of the brown bullhead ranged from 40 to 2,500 p.p.m. To prevent the possibility of increasing the present hazard of DDD poisoning of wildlife, Clear Lake will receive no further treatment with DDD.

In laboratory tests to control chemically other midge larvae, Hilsenhoff (1959) screened 16 commercially available organophosphate insecticides to determine their relative toxicity. Dipterex and malathion incorporated into granules produced an 80-percent mortality of the larve at concentrations of 0.1 pound per acre of the technical material. These insecticides have a low toxicity to fishes, waterfowl and mammals. Field tests on Lake Winnebago, Wis., with malathion granules, however, did not prove conclusive at low concentrations; the feasibility of chemical control on a large body of water with a nonaccumulative insecticide is questionable.

Various species of midges have become established as significant nuisance problems in San Mateo County and many other suburban areas throughout California (Whitsel et al., 1963). Midge production at all stations in a study of the problem area, was preceded by a pronounced increase in accumulated organic matter. Water known to be polluted with sewage wastes was found to have over 1,100 larve per square foot of substrate. Man-made drainageways were found to produce greater midge infestations than natural drainage creeks. Localized chemical applications were reported to be successful in control practices. "Chemical control by granular Baytex 0.1 and 0.2 pound per acre provided fairly effective reduction of *Chironomus* larvae in impounded and slowly moving waters, with no harm to mosquito fish, *Gambusia affinis*. Granular dieldrin showed promising control in slowly moving waters, with little harm to Gambusia and aquatic invertebrates at 0.5 pound per acre." Patterson and von Windeguth (1964) described Baytex as one of the most promising chemicals for use as a larvicide against chironomid midges. In laboratory experiments, they found that a granular formulation at the recommended larvicidal rates exhibited no overt toxic effects on fresh water copepods, ostracods, hydra, annelid worms, snails, clams or fish over a 4-month period. There was indication that Baytex was very toxic to midge larvae and to *Cladocera*.

In a recent study of the biology of midges in Lake Winnebago, Wis. (Hilsenhoff 1966) found that eggs of *Chironomus plumosus* (Linnaeus) are laid on the lake surface in masses averaging 1,676 eggs. These masses absorb water, swell, and sink to the lake bottom, where the eggs hatch in 3 to 14 days. Larval stages range from 1.40-mm., colorless, first instars to 30-mm, dark red, fourth instars. The newly hatched first instars are free-swimming and positively phototrophic. All instars, except perhaps the first, construct U-shaped tubes in the bottom mud and, at temperatures above 5° C., feed indiscriminately by "filter feeding." Female larvae must weigh 60 mg. or more to pupate, but male larvae will pupate when they weigh 48 to 56 mg. Emergence may occur at any hour, day or night, but is most prevalent just before sunset. Newly emerged flies fly weakly with the wind, eventually accumulating on the lee shore. Swarms of males form about 1 hour before sunrise and disperse about 1 hour after sunset in response to light. The swarms, typically containing several thousand flies, orient over objects that contrast with the background. Females fly into the swarms for mating, which occurs most commonly in the early morning. Mated females, after a preoviposition period of 1½ to 5 days, fly out over the lake to oviposit, extruding their egg masses onto their hind legs while in flight; oviposition occurs commonly at all hours of day or night. The larvae are eaten by many fish and by 1 species of leech, are parasitized by a microsporidian, and are occasionally killed by unknown diseases. There are normally 2 generations a year in Lake Winnebago. Overwintering fourth-instar larvae pupate and emerge during mid-May; their progeny emerge from mid-July to early September. Rate of development and time of emergence are dependent on mud temperatures. If unknown stimuli necessary for pupation are absent, a generation may be delayed or entirely missed.

Moore (1923) describes methods of leech control through freezing in their winter quarters. As water temperatures fall with the onset of winter, leeches become more and more sluggish and finally bury themselves in the mud or beneath stones on the bottom of shallow water. Leeches are readily killed by exposure to a temperature of 20° F. for a few hours. When the first thin ice starts to form and it is certain that the water temperature has attained its minimum, Moore recommends that the water be drawn off as rapidly as possible until the water level is lowered 4 feet, and that this level be maintained for at least 5 or 6 weeks during the coldest part of the winter. He reasons that, under these circumstances, the exposed flats would be frozen hard to a considerable depth, and temperatures would be well below the fatal minimum for the imprisoned leeches. This method of control was effective in Carr Pond, Palisades Interstate Park near New York City. Pennak (1953) states that leeches may be temporarily controlled in localized bathing beach areas by applying 100 pounds of powdered lime per acre per day in the shallows.

In general, chemical controls have not proved successful, although chemicals such as copper sulfate will kill leeches that are exposed to it. The measures employed in snail control have been used with some success in leech control. Weekly distribution of a slurry composed of 10 pounds of copper sulfate and 5 pounds of copper carbonate or lime per acre of bathing area has shown some success. Chelated copper compounds applied marginally as a spray at concentrations sublethal to fish have also been of value.

Regulations

Most states have laws or regulations to regulate specifically the use of pesticides to control nuisances in aquatic habitats. Some States regulate only the commercial applicators; others regulate all chemical users. Before chemicals are applied to control any aquatic pest, it is well to check with the appropriate state authority to ascertain the legality of the proposed chemical application.

The application of a chemical to water involves certain hazards that must be understood and against which public rights must be protected. Factors that must be considered are the short- and long-range toxicity to all aquatic life; the deposition and possible accumulation of the chemical upon the lake bottom, and the subsequent reaction upon the community of bottom organisms; the impact resulting from the destruction of too much biological growth at one time; and the possible disturbance or impairment of the general aquatic environment.

De Vaney (1968) cites the basic policy of the Department of the Interior with respect to the use of pesticides as follows:

> "It is essential that all pesticides, herbicides, and related chemicals be applied in a manner fully consistent with the protection of the entire environment. Any contemplated use of these chemicals must take into account both known and possible environmental effect. The guiding rule for the Department shall be that where there is a reasonable doubt regarding the environmental effects of the use of a given pesticide, herbicide, or other chemical, no use should be made."

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APPENDIX

ACRES

Hectares × 2.471 = Acres.
Square Meters × 2.471×10^{-4} = Acres.
Acres × 4047 = Square meters
Acres × 43,560 = Square feet.
Acre-feet × 325,851 = Gallons.
Grams per square meter × 8.922 = Pounds per acre.
Kilograms per hectare × 0.8922 = Pounds per acre.
Milligrams per square centimeter × 89.22 = Pounds per acre.
Milligrams per cubic meter × 2.72×10^{-3} = Pounds per acre-foot

AREA

Circle —Square of the diameter × 0.7854.
Rectangle —Length of the base × height.
Sphere —Square of the radius × 3.1416 × 4.
Square —Square the length of one side.
Trapezoid —Add the two parallel sides × height ÷ 2.
Triangle —Base × height ÷ 2.

CIRCUMFERENCE

Circle—Diameter × 3.1416

DISSOLVED OXYGEN

Micromoles per liter × 32×10^{-3} = Milligrams per liter.
Millimoles per liter × 32 = Milligrams per liter
Micromoles per microliter × 32×10^{3} = Milligrams per liter
Millimoles per square meter × 2848×10^{-4} = Pounds per acre.

DOSAGE FORMULA (Chemical)

Length (ft.) × Width (ft.) × Average Depth (ft.) × 62.4 × Desired Concentration in ppm × 10^{-6} = Pounds of active Material Needed.

Speed of Boat (feet per hour) × Width of Spray Pattern (feet) × Depth of Calculated Treatment (feet) × 62.4 × Desired Concentration in ppm × 10^{-6} = Pounds of Active Material Needed Per Hour.

FEET

Fathoms × 6.08 = Feet.
Meters × 3.281 = Feet.
Acres × 43,560 = Square feet.
Square meters × 10.76 = Square feet.
Square feet × 929×10^{-4} = Square meters.
Gallons × 1337×10^{-4} = Cubic feet.
Cubic feet × 7.48 = Gallons.
Gallons per minute × 2.228×10^{-3} = Cubic feet per second.
Cubic feet per second × 448.8 = Gallons per minute.
Million gallons per day × 1.547 = Cubic feet per second.
Cubic feet per second × 6463×10^{-4} = Million gallons per day.

GALLONS

Acre-feet	×	325,851	=	Gallons.
Cubic feet	×	7.48	=	Gallons.
Liters	×	2642×10^{-4}	=	Gallons.
Pounds of water	×	1198×10^{-4}	=	Gallons of water.
Gallons per minute	×	1440	=	Gallons per day.
Gallons of water	×	8.345	=	Pounds of water.
Gallons	×	1337×10^{-4}	=	Cubic feet.
Gallons	×	231	=	Cubic inches.
Gallons	×	3.785	=	Liters
Cubic feet per second	×	6463×10^{-4}	=	Million gallons per day.
Cubic feet per second	×	448.8	=	Gallons per minute.
Gallons per minute	×	2.228×10^{-3}	=	Cubic feet per second.
Million gallons per day	×	1.547	=	Cubic feet per second.
Parts per million	×	8.345	=	Pounds per million gallons.

MILES

Kilometers	×	6214×10^{-4}	=	Miles.
Statute Miles	×	1.15	=	Nautical miles.
Miles	×	1.609	=	Kilometers.
Nautical Miles Per Hour	×	1.0	=	Knots.

PHOSPHORUS

microgram atoms phosphorus per gram (μg-atP/g) = 31 parts per million phosphorus (P).

microgram atoms phosphorus per liter (μg-atP/1) = 31 parts per billion phosphorus (P).

phosphorus pentoxide (P_2O_5) × 0.436 = phosphorus (P) equiv.

phosphate (PO_4) × 0.326 = phosphorus (P) equiv.

PARTS PER MILLION

Milligrams per liter	×	1.0	=	Parts per million.
Grams per liter	×	1000	=	Parts per million.
Micrograms per liter	×	10^{-3}	=	Parts per million.
Micrograms per gram	×	1.0	=	Parts per million.
Cubic centimeters per liter	×	1.4545	=	Parts per million.
Milligrams per gram	×	10^{3}	=	Parts per million.
Cubic millimeters per liter	×	1.0	=	Parts per million (volume).
Cubic microns per milliliter	×	10^{-6}	=	Parts per million (volume).
Parts per million	×	8.345	=	Pounds per million gallons.

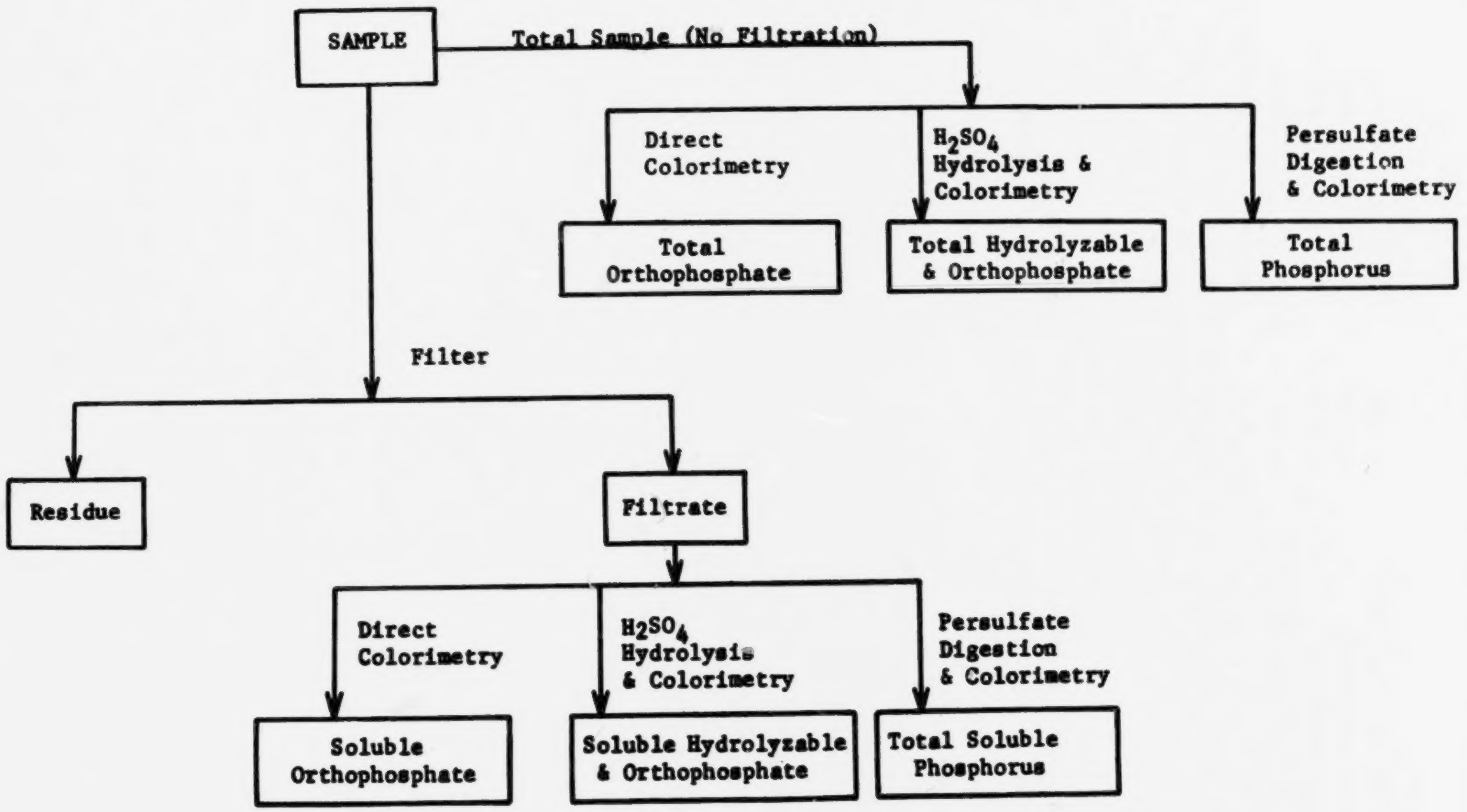
SAMPLE
Total Sample (No Filtration)
Direct Colorimetry
Total Orthophosphate
H_2SO_4 Hydrolysis & Colorimetry
Total Hydrolyzable & Orthophosphate
Persulfate Digestion & Colorimetry
Total Phosphorus
Filter
Residue
Filtrate
Direct Colorimetry
Soluble Orthophosphate
H_2SO_4 Hydrolysis & Colorimetry
Soluble Hydrolyzable & Orthophosphate
Persulfate Digestion & Colorimetry
Total Soluble Phosphorus

Figure 86. Analytical Scheme for differentiation of phosphorus forms. (From FWPCA Official Interim Methods for Chemical Analysis of Surface Waters, September 1968.)

NITRATE (NO_3) × 0.226 = nitrogen (N) equiv.

POUNDS

Milligrams per square meter........ × 8922 = Pounds per acre.
Grams per square meter............ × 8.922 = Pounds per acre.
Kilograms per hectare.............. × 0.8922 = Pounds per acre.
Milligrams per square centimeter... × 89.22 = Pounds per acre.
Milligrams per liter................. × 2.72 = Pounds per acre-foot.
Milligrams per cubic meter......... × 2.72×10^{-3} = Pounds per acre-foot.
Micrograms per square meter....... × 8.92×10^{6} = Pounds per acre.
Acre-feet of water.................. × 2.7×10^{6} = Pounds of water.
Gallons of water.................... × 8.345 = Pounds of water.
Parts Per Million × Cubic Feet Per Second × 5.4 = Pounds per day.
(Gallons per minute × 2.228×10^{-3} = Cubic feet per second).
Parts per million × 8.34 × gallons per day × 10^{-6} = Pounds per day.
(Gallons per minute × 1440 = Gallons per day).

STANDARD UNITS

Areal standard units = $20\mu \times 20\mu = 400\mu^2$
Cubic standard units = $20\mu \times 20\mu \times 20\mu = 8000\mu^3$
Cubic standard units × 8×10^{-3} = parts per million by volume

VOLUME

Cone —Square the radius of the base × 3.1416 × height ÷ 3.
Cube —Cube the length of one edge.
Cylinder —Square the radius of the base × 3.1416 × height.
Pyramid —Area of the base × height ÷ 3.
Sphere —Cube the radius × 3.1416 × 4 ÷ 3.

Temperatures—Centigrade to Fahrenheit*

Temp. ° C.	0	1	2	3	4	5	6	7	8	9
0	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2

*Temperatures in degrees Centigrade expressed in left vertical column and in top horizontal row; corresponding temperatures in degrees Fahrenheit in body of table. (From: Welch, P.S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc.)

Temperatures—Fahrenheit to Centigrade*

Temp. ° F.	0	1	2	3	4	5	6	7	8	9
30	−1.11	−0.56	0.00	0.56	1.11	1.67	2.22	2.78	3.33	3.89
40	4.44	5.00	5.56	6.11	6.67	7.72	7.78	8.33	8.89	9.44
50	10.00	10.56	11.11	11.67	12.22	12.78	13.33	13.89	14.44	15.00
60	15.56	16.11	16.67	17.22	17.78	18.33	18.89	19.44	20.00	20.56
70	21.11	21.67	22.22	22.78	23.33	23.89	24.44	25.00	25.56	26.11
80	26.67	27.22	27.78	28.33	28.89	29.44	30.00	30.56	31.11	31.67
90	32.22	32.78	33.33	33.89	34.44	35.00	35.56	36.11	36.67	37.22
100	37.78	38.83	38.89	39.44	40.00	40.56	41.11	41.67	42.22	42.78

*Temperatures in degrees Fahrenheit expressed in left vertical column and in top horizontal row; corresponding temperatures in degrees Centigrade in body of table. (From: Welch, P.S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc.)

BIO-ASSAY DOSAGE CHART

For Preliminary Screening of an Effluent Waste

Percent of Waste in test jar	Waste added (ml)	Dilution water added (ml)
100	2,500	0
75	1,875	625
56	1,400	1,100
32	800	1,700
18	450	2,050
5.6	140	2,360
1	25	2,475
0	0	2,500
Total (ml)	7,190	12,810
Gallons required	2	3 1/3

BIO-ASSAY DILUTION CHART

A Guide to the Selection of Experimental Concentrations, Based on Progressive Bisection of Intervals on a Logarithmic Scale

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
10.0				
				8.7
			7.5	
				6.5
		5.6		
				4.9
			4.2	
				3.7
	3.2			
				2.8
			2.4	
				2.1
		1.8		
				1.55
			1.35	
				1.15
1.0				

DILUTION TABLE

Concentration Desired			To prepare solutions of concentrations indicated at left, take number of milliliters of stock solution shown below, and make up to one liter with suitable dilution water.				
%	ppm or mg/L	ppb or µg/L	Stock sol: 10% 100 gm/L	Stock sol: 1% 10 gm/L	Stock sol: .1% 1 gm/L	Stock sol. :01% .1 gm/L	Stock sol: .001% .01 gm/L
100.	1,000,000						
10.	100,000		1,000				
5.6	56,000		560				
3.2	32,000		320				
1.8	18,000		180				
1.0	10,000		100	1,000			
.56	5,600		56	560			
.32	3,200		32	320			
.18	1,800		18	180			
.1	1,000		10	100	1,000		
.056	560		5.6	56	560		
.032	320		3.2	32	320		
.018	180		1.8	18	180		
.01	100		1.0	10	100	1,000	
.0056	56			5.6	56	560	
.0032	32			3.2	32	320	
.0018	18			1.8	18	180	
.001	10			1.0	10	100	1,000
.00056	5.6				5.6	56	560
.00032	3.2				3.2	32	320
.00018	1.8				1.8	18	180
.0001	1.0	1,000			1.0	10	100
.000056	.56	560				5.6	56
.000032	.32	320				3.2	32
.000018	.18	180				1.8	18
.00001	.10	100				1.0	10
.0000056	.056	56					5.6
.0000032	.032	32					3.2
.0000018	.018	18					1.8
.000001	.010	10					1.0

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